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NUCLEAR WINTER AND ITS IMPLICATIONS

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NUCLEAR WINTER AND ITS IMPLICATIONS

WEDNESDAY, OCTOBER 2, 1985

U.S. SENATE,
COMMITTEE ON ARMED SERVICES,
Washington, DC.

The committee met, pursuant to notice, at 9:30 a.m., in room SR-222, Russell Senate Office Building, Senator Barry Goldwater (chairman) presiding.

Present: Senators Goldwater, Warner, Humphrey, Cohen, Quayle, Wilson, Denton, Nunn, Hart, Exon, Levin, Dixon, and Glenn.

Staff present: James F. McGovern, staff director and chief counsel; Arnold L. Punaro, staff director for the minority; Jeffrey H. Smith, minority counsel; Robert E. Bayer, Robert F. Bott, Douglas R. Graham, and William E. Hoehn, Jr., professional staff members; Russell C. Miller, research assistant; and Karen A. Love, staff assistant.

Also present: Gerald J. Smith, assistant to Senator Goldwater; Robert P. Savitt, assistant to Senator Cohen; James M. Bodner, assistant to Senator Cohen; Henry D. Sokolski, assistant to Senator Quayle; Mark J. Albrecht, assistant to Senator Wilson; Allan W. Cameron and Deforest Hamilton, assistants to Senator Denton; Alan Ptak, assistant to Senator Gramm; Francis J. Sullivan, assistant to Senator Stennis; Janne E. Nolan, assistant to Senator Hart; Jeffrey B. Subko, assistant to Senator Exon; John Keeley, assistant to Senator Levin; Gregory B. Craig, assistant to Senator Kennedy; Charles C. Smith, assistant to Senator Dixon, and Phillip P. Upschulte, assistant to Senator Glenn.

OPENING STATEMENT BY SENATOR BARRY GOLDWATER, CHAIRMAN

Chairman GOLDWATER. The meeting will come to order.

This morning, the committee meets to receive testimony on the "nuclear winter" hypothesis, which postulates detrimental global climatic effects resulting from the lofting of sufficient smoke, dust, and other materials following nuclear explosions.

This will be the first of two hearings intended to follow up on the report by the Department of Defense on this subject that was submitted in response to the provisions of the fiscal year 1985 Defense Authorization Act.

Today's hearing will consist of two panels. The first panel, consisting of Dr. C.M. Gillespie of the Defense Nuclear Agency, will provide an updated assessment of the current scientific findings with regard to nuclear winter and related phenomena.

This testimony should provide members a summary of the important factors that underlie the predictions of adverse climatic effects, including the models involved, and the certainty of the data used.

Dr. Gillespie will also be prepared to address the U.S. Government's global effects research plan.

The second panel consists of three witnesses who will provide testimony reflecting their own expert perspectives. Dr. Mark Harwell, from the Center for Environmental Research at Cornell University, and a contributor to the recent report of a panel of international scientists, will address the vulnerabilities of ecological and agricultural systems to the climatic effects potentially associated with nuclear explosions.

Mr. Leon Sloss, who has participated in the formulation of U.S. targeting policy, will address the nuclear winter hypothesis from the perspective of targeting policy implications.

And Dr. Leon Goure, the Director of the Center for Soviet Studies at Science Applications International Corp., will address the Soviet contribution to nuclear winter research, and whether Soviet policymakers have been influenced by such research.

There is no doubt in my mind, and I am sure there is no doubt in the mind of anyone in this room, that a nuclear war would be a catastrophe of such great proportions that it absolutely must be prevented. That has been the centerpiece of our deterrence philosophy since the dawn of the nuclear competition, and one that this committee has supported, and continues to support through the modernization of our deterrent force, both conventional and nuclear.

I believe that a greater public awareness of what is certain and what is uncertain about the effects of nuclear war will contribute to a more informed debate of the relevant policy issues, and will serve to strengthen the Nation's commitment to doing whatever is required to maintain deterrence.

I welcome our witnesses here this morning. Following opening remarks that other members of the committee would care to make, I would ask Dr. Gillespie to begin. I would expect the testimony of each witness to take approximately 10 minutes, and there will be an opportunity for questions following each of the panels.

The committee has received prepared statements from each of the witnesses, and they may present their statements or summarize them as they see fit.

I have to say that I am extremely interested in this. I have spent two wonderful days with Dr. Alvarez, the Nobel physicist, discussing the Nemesis theory or what happened to the dinosaurs. The fact that every 26 million years, the elliptical orbiting of the Sun by a star that up to now has not been located, fascinated me.

I am a firm believer that there could be such a thing as a nuclear winter just as we had a winter caused by a portion of a planet hitting this Earth. Thank God, it has 13 million more years to go before that might happen again.

My concerns are not really about myself—I won't be here. I do believe firmly in the scientific possibility.

Senator Cohen?

Senator **Cohen**. Senator Goldwater, I want to thank you for scheduling these hearings. I won't take the time to make an opening statement, but I think they are terribly important not only to this country and the world, but at least to start the exploration of questions that I feel have been either ignored or diminished in terms of support.

So, I would like to thank you for holding these hearings. I will have a number of questions to ask.

Chairman **Goldwater**. Senator Warner?

Senator **Warner**. Thank you, Mr. Chairman.

I join in commending my distinguished colleague from Maine who has taken the initiative in this field. It is one of great importance and commands the attention of the committee and the Senate as a whole.

Chairman **Goldwater**. The prepared statement of Senator Dixon will be inserted in the hearing record at this point.

[The prepared statement by Senator Dixon follows:]

Prepared Statement by Senator Alan Dixon

Mr. Chairman, it becomes clearer with each passing day that the effects of a nuclear war may be even more devastating than previously estimated. New scientific research findings suggest agricultural and ecological stress which would result in massive famine. In addition, new medical findings present a bleak picture for survivors who would be subjected to a hostile environment of disease.

In light of these findings, it is of vital importance, in the interest of the world as well as this country, to continue research on the biological, medical, ecological, and agricultural consequences of a nuclear war. There are still many unanswered questions. Research must be continued in order to facilitate prudent policy making.

With regard to the upcoming Geneva conference, it is especially important for the American and Soviet governments to have an understanding of the grave consequences which confront them. It is only in understanding the reality of nuclear devastation that we have a hope of relieving the world of the threat of this cateclysmic event.

Chairman **Goldwater**. Dr. Gillespie, you may proceed in any way you wish.

STATEMENT OF C.M. GILLESPIE, ASSISTANT TO THE DEPUTY DIRECTOR (SCIENCE AND TECHNOLOGY) FOR TESTING, DEFENSE NUCLEAR AGENCY

Dr. **Gillespie**. Thank you very much, Senator Goldwater.

I appreciate very much the opportunity to come before you this morning to talk about the scientific aspects of the nuclear winter theory and in particular the climate aspects of that theory. I would like to cover three things this morning.

First, is to run through rather briefly a description of what the nuclear winter hypothesis is, then to go into a discussion of the degree and nature of the uncertainties in predicting climate effects that you have heard a great deal about. Then, to discuss the evolution of our understanding of these effects over the last 4 years. And, finally, to put the matter in some degree of perspective.

Now, let me say that the role of the Defense Nuclear Agency in this matter is to manage scientific research into the climatological effects associated with what we call nuclear winter. As such, we have no position on the science of nuclear winter, much less on the policy implications that flow from those science considerations.

Our job is to narrow the balance of uncertainty and to indicate what are the major scientific and technical aspects of the problem. In what I will say, I have tried to make it as nearly the general consensus of the scientific community as I am able to do that.

Nevertheless, in some cases I will express some personal opinions and I think it will always be clear when it is that I am expressing a personal opinion as distinct from, I believe, the consensus of the community. Of course, you realize that in the international community I am talking about the consensus is something that has to be interpreted broadly.

The nuclear winter effect, of course, begins with a nuclear exchange. The assumption one makes as to what this exchange is is just that. It is not part of the science of nuclear winter; it is an assumption you make that is an input parameter.

There are really four primary variables that one puts into this assumption as to the nature of the nuclear exchange. The number of weapons, their yield, the height of burst, and perhaps most important of all, the nature of the target, in particular whether it is an urban target, in other words, a city, or a nonurban target such as a missile silo.

I am going to primarily, in talking about the effects caused by these nuclear explosions, refer to smoke. Now, we all know that the nuclear winter effects are produced by a combination of smoke and dust, but in order to keep things short and not go into unwarranted technical detail, I will just generally refer to smoke with the understanding that the dust is included in some appropriate way.

After the nuclear explosions have gone off, one is left with fires burning. It is the smoke from these fires that resides in the atmosphere for long periods of time that causes the nuclear winter effect. How much smoke is produced is the first very important consideration. This is a function of the amount of fuel present, how much of it burns and finally, for that that does burn, how much smoke it produces.

As I will indicate later, the nature of that smoke is also critically important.

Following this initial production of smoke, one has many, depending on the scenario that you have assumed, many individual point sources of smoke being injected into the atmosphere. The level at which it is injected into the atmosphere is important. At this point two processes begin to take place and there is an interplay between them.

The first is the gradual spreading of this smoke from very localized areas to a much more general global or at least hemispheric cover. While this is going on another process is taking place, and that is the removal of this smoke from the atmosphere.

It is well known that the atmosphere is a very powerful engine for cleansing itself. Certainly one of the most obvious ways that we are all familiar with is that it rains and that cleans the air. There are also many other processes that go on.

Now, it is essential, in order to have a nuclear winter, that the smoke be widely spread. I believe that is clear.

Now that you have smoke spread around, what happens is finally we get to what causes the cooling. That is the absorption of sunlight by the smoke at very high levels in the atmosphere.

What keeps the Earth warm, what makes it habitable, is the fact that sunlight is absorbed mostly at the surface of the Earth. That in turn warms the air immediately near the surface.

In the nuclear winter case the sunlight is being absorbed at a few tens of thousands of feet or higher. As a result, the surface of the Earth is never warmed, it cools, and thus, the global climatic cooling that we call nuclear winter.

Now, the amount of sunlight absorption is, of course, obviously the critical effect and in the nuclear winter case we are talking about absorption of anywhere from 10 or 20 percent to virtually 100 percent of the Sun.

Now, the cooling is the first and most dramatic manifestation of the nuclear winter phenomena. It was the one first predicted and is certainly the one I believe that is of the most central concern.

However, as we have gone through the last 3 or 4 years of research, I think we have come to a realization that there is probably another effect that also may be of great significance, particularly if the cooling is not as great as predicted, and that is just the fact that we have totally changed the normal patterns of behavior of the atmosphere.

We have changed the circulation pattern, we have probably drastically altered the precipitation patterns. In other words, the weather is going to be different in the nuclear winter environment.

I think Mr. Harwell, who follows me, will address some of the possible implications of that.

Now, there are some other side issues.

Senator COHEN. Did you say he will discuss the impossible implications?

Dr. GILLESPIE. The possible, not impossible, certainly not.

Let me mention some of the other things that we now feel fairly sure about with respect to nuclear winter. They were all things that were speculated upon early on, a few years back. Because of the modeling work we have done, we now feel that there are certain things that we can predict with fair confidence, at least qualitatively.

The first is the effect of the ocean. The oceans cover about three-quarters of the surface of the Earth and they are a tremendous reservoir of heat. The land surface will cook very rapidly. In fact, in our experience it cools almost overnight. That is not true of the oceans.

Oceans are a heat reservoir that will ameliorate the severe temperature depressions for a period of months.

Now, along with that observation goes along the clear indication that there is a very distinct difference between coastal regions and deep continental interiors. The effects are shown to be much more in the deep continental interior.

Another thing we are seeing is the seasonal effect. For any given injection of smoke, the temperature depression, the climatic changes, are much more severe in the summertime than they are in the winter.

That results simply from the fact that there is less sun coming in in the winter to begin with, so there is less to interfere with and, of course, it is also colder, so the temperature, the absolute temperature drop would be predicted to be less.

Another effect that was discussed early on is whether a Northern Hemisphere war would have implications for the Southern Hemisphere. It was speculated there would be a transport of debris into the Southern Hemisphere, but it was not very well defined how this would take place or to what extent.

Certainly there are still major uncertainties, but the global climate modeling we have done has shown a clear mechanism for the transport of smoke into the Southern Hemisphere. I think this is now a very credible part of the nuclear winter hypothesis.

Now, the effect of all of this—I have thus far now sort of described and sketched the climate effects—the effect of all of this, of course, is the way it affects the population of the world through the effect on the ecology and agricultural production, which ultimately leads to famine and starvation.

Again, this is not a major area that we are looking at right now as part of our program, and I say this for the national program that is looking at nuclear winter. It has, however, recently been looked at in some detail.

What I believe is probably the first very careful, thorough approach to this subject is in a report that was released in preliminary form 2 weeks ago, the so-called Scope [Scientific Committee on Problems of the Environment] report.

Again, Dr. Harwell is a principal author of the biological aspects of that report and you will hear from him.

Let me very quickly pick up the few side issues here and then go on to uncertainties.

There is a possibility that significant amounts of toxic chemicals are produced, particularly in the burning of plastics and hydrocarbons. Along with this goes the increase in ultraviolet radiation to the surface of the Earth.

These are indeed legitimate areas of concern, but they are ones about which we know relatively little right now and it is something that does need to be looked at.

There has been talk of triggering some sort of climatic catastrophe such as another ice age, but as yet I have seen no plausible hypothesis that illustrates such an effect occurring.

There initially was talk about fallout being somehow different than what we originally had thought. I think the issue of global fallout—and I am specificaly talking about global fallout, not the near term or immediate area effect of fallout which are well understood—the global aspects of fallout do not appear to be terribly significant. The doses are fairly low and at most you would expect some small increase in the normal rate of cancer caused by that fallout.

Let me now talk about some of the studies that have been done. In particular, I will refer to the baseline cases that have been addressed in three major quantitative studies of nuclear winter. Those three studies are the TTAPS studies that were initially published 2 years ago, The National Academy of Science study that was sponsored by DNA and published a year ago and a recent

SCOPE study which has not been formally published yet, but which will be very shortly and which has been made available in preliminary form.

All of these studies considered a so-called baseline case, a baseline scenario of a nuclear exchange. In general, those exchanges involved 5,000 to 6,000 megatons of total yield detonated. Some 10,000 to 12,000 nuclear explosions took place in those baseline cases. The targets were a mix of counterforce targets—I will use that to mean silos and really nonurban targets, a mixture of targets of that sort—and cities. In fact, the attack on cities resulted, in general, in the burning of about one-third, a quarter to a half, let us say, of all of the urban area in the Northern Hemisphere.

There are perhaps 20 parameters that must then go into your analysis of the climate effects. In assessing the climate effects, the people who did these studies attempted to take their best central value for these various parameters. So, the baseline cases they attempted to come up with are what they believe to be nominal values, if you will.

What they predicted was anywhere from 150 to 250 million tons of smoke injected into the atmosphere. The temperature drops that resulted from this smoke injection were very large. They were many tens of degrees Fahrenheit. This is a summertime situation I am talking about here.

It is these baseline scenarios that form the basis for most of the considerations of nuclear winter.

Now let me talk about some of the uncertainties.

I have already mentioned that the exchanges are very large, involving perhaps half of the total strategic and theater nuclear arsenals of the world. Attacks of this size certainly imply that escalation control and any attempt at moderation has been a failure.

Now, it is my feeling that these baseline scenarios tend to be upper limits for any realistic assessment of what the exchange scenarios could be.

The reason I make that statement is simply the fact that the primary targets for strategic nuclear exchanges are the other side's nuclear weapons. I would expect that large numbers of nuclear weapons would be destroyed in the engagement.

So, I don't think it likely that the exchanges are going to be very significantly greater than the baseline cases that I have just talked about.

Now, the uncertainty in the production of smoke. I think there has been one significant research finding since the earlier studies here and that has to do with the smoke from nonurban targets, so-called wildland targets.

These are the kinds of targets that would be attacked when you have a counterforce exchange where the targets are missile silos, airfields, radar installations, true military targets, and defined as being those military targets which are not co-located with cities.

That is the important point I am trying to make here. These are targets that do not involve the burning of cities. Initial estimates for the amount of smoke production in this case were in one case 80 million tons of smoke.

A very careful analysis of targets of this sort has lowered those estimates by a factor of anywhere from 30 to 300, depending on the time of year. So, that has in no sense of the word, let me emphasize, made nuclear winter go away. It has merely changed the emphasis and it put the emphasis on attacks of cities and on hydrocarbons in particular.

Senator **COHEN**. In reducing that figure, you said it depends on the season.

Did you factor in summer? Did you assume it was summer?

Dr. **GILLESPIE**. Yes, the analysis was actually done month by month taking into account weather, and other seasonal factors, and it was done statistically for 3,500 specifically identified targets. The factor of 30 reduction refers to summer when smoke production was greatest.

If I looked at all the uncertainties in smoke production and particularly the uncertainties that surround what happens when cities burn, it is my estimate that the range of uncertainties is possibly as large as a factor of 5, either greater or less, from the baseline case. This is the amount of smoke just initially produced and available to generate climatic effects.

Next comes the spreading and the concomitant removal processes that take place simultaneously. In the interest of time, let me not go into the features of that except to say that the recent work that has been done shows that there is persistent patching in the cover of smoke.

We do, indeed, see that smoke covers the Northern Hemisphere and moves into the Southern Hemisphere to some extent, but it remains patchy to some extent during this whole process. We also see a gradient from the North Pole southward in the density of smoke.

I would again estimate that an effective uncertainty in the amount of smoke that is associated with the spreading process and in particular the removal process, processes by which the atmosphere cleanses itself, is again a factor of five, possibly going in either direction.

Finally, there is the issue of solar attenuation and the cooling that results from that.

There are two types of uncertainties here.

First, is just the uncertainty as to the ability of smoke to absorb sunlight, how effective an absorber. This is very dependent on the physical and chemical form of the smoke. How it has changed as it resides in the atmosphere is a matter that has some considerable uncertainty attached to it.

The second part of this is the uncertainty just in our ability to predict climate effects and changes. Again, I will estimate that there is a net uncertainty that is the equivalent of a factor of 5 either way in smoke production.

What I have done then is, aside from the magnitude of the nuclear exchange, I have identified three broad scientific areas to each of which I have assigned roughly the factor of 5 uncertainty either way in severity compared to the baseline cases that I have described.

Now, it is not appropriate in this case to then say that the total uncertainty is the product of those, 5 times 5 times 5. That, I believe, is not appropriate in this case.

The uncertainty is not that large, but I believe the uncertainty that is there is at least a factor of 10. I think it is greater than a factor of 10.

Now, let me talk about what the effects of this kind of uncertainty will be on the baseline temperature.

First, there is the case of what if the effects are worse then the baseline?

What is important in that issue is that the baseline nuclear winter effects are as predicted, about as bad as they can get. If you increase the smoke loading or increase the attenuation coefficient or decrease the rate at which pollutants are removed from the atmosphere, it is very difficult to make the temperature drops that have been predicted go very much lower.

The effects will last somewhat longer, but this is a nonlinear process and the effects will not get significantly worse.

On the other hand, if the uncertainty is such that you reduce the effects, then you are in a somewhat more fortunate situation. That is to say, if the amount of smoke that is up there goes down, the temperature drops are reduced.

Now, can I attach quantitative numbers to this? I think you have to decrease the amount of smoke over these baseline predictions by a factor of 4 or 5 and if you do that, you will get very significant reduction in the temperature drop.

Now, I will comment very briefly on the biological consequences.

Certainly for temperature drops in the baseline case, the many tens of degrees Fahrenheit drops, lasting for weeks or even months; there can be no doubt that that is agriculturally a biological catastrophe. If that occurs in the spring or summer, there would hardly be any doubt that there will be no food production for that year.

The case of very much reduced temperature drops which I believe to be somewhat more likely than a severe drop, will probably also produce very significant effects, although I would expect them certainly to be much less.

So, in my own thinking I have constructed a hierarchy of consequences of war that I think helps me to understand better the kinds of things we are talking about here. This is a hierarchy of consequences starting with things that we know would happen and progressing to things of less and less certainty.

First, there is the direct consequences of nuclear exchange. You postulate whatever exchange you wish to consider and these effects follow without any doubt whatever. They are certain.

Furthermore, they are relatively well predicted. Casualties can be relatively well predicted for a given scenario. These are the direct effects of nuclear explosions, including fallout.

Then, almost as certain is another set of effects that will occur. These are indirect effects that have to do with the disruption of commerce and trade. Specifically, much of the world agricultural system depends upon fertilizer and fuel.

Many people in the world depend upon imported food and in the event of a war, whether it is nuclear or nonnuclear, there will be a major disruption of all of these activities that I have described. The effects will be particularly severe on the less developed countries, the so-called Third World.

I think from reading the executive summary of the Scope report, that one important contribution to the nuclear winter discussion is the very clear realization in pointing out in that report that these effects will occur. Quantifying them is another matter, but these effects are also quite sure.

At a somewhat less level of surety is the possibility of a relatively mild nuclear winter. By relatively mild, I mean a few degrees temperature drop lasting for a few weeks. There would go along with this something that is less understood at this point, is more speculative, but also potentially damaging, and that is wide variations in weather patterns.

The consequences of this are to me much less certain and have not been looked at as much. I believe the Scope report will contribute significantly to our understanding.

At a lesser level still of probability of occurence, I think are the very severe, many tens of degrees, temperature drops that were initially predicted. There, of course, the consequences are fairly clear, I think.

Except for places in the Southern Hemisphere where even for this case you don't see such severe effect, the effect on agriculture would be disastrous.

Finally, I would add a fifth thing just so that I can discard it. Initially in the nuclear winter discussion there was much reference made to the extinction of mankind. I think there is no foundation for such a speculation at this point. Even in the worst cases it is clear that in the Southern Hemisphere the effects are much, much less severe.

Senator, that concludes the comments I wanted to make. I will be happy to answer any questions.

[The prepared statement of Dr. Gillespie follows:]

PREPARED STATEMENT OF C.M. GILLESPIE, DEFENSE NUCLEAR AGENCY

Mr. Chairman and members of the subcommittee, I appreciate the opportunity to appear before this committee on the subject of the "nuclear winter" hypothesis and global effects research. There has been significant progress over the last two years, but there are still many and considerable uncertainties remaining. I will first describe our understanding of results achieved to date, with emphasis on the limitations of the early predictive models and some of the major improvements achieved, and then I will describe our conclusions with respect to continued research in global effects.

There is an appreciation, generally accepted within the defense community, of the importance of global climate effects, sometimes referred to as "nuclear winter." It is first essential to improve our understanding of the hypothesis which asserts, in its most rudimentary form, that if sufficient material, smoke, and dust created by nuclear explosions are lofted to sufficient altitude, and remain at that altitude for protracted periods, detrimental global climatic effects would occur.

We have very little confidence in our current ability to predict this phenomenon quantitatively, either in terms of the amount of sunlight obscured and related temperature changes, the duration of such consequences, or the levels of nuclear attacks which might initiate such consequences. We do not know whether the long-term consequences of a nuclear war—of whatever magnitude—would be the often-postulated months of subfreezing temperatures, or a considerably less severely perturbed atmosphere, with widely ranging and unpredictable weather. As the Defense Science Board Task Force found in their interim report:

"The uncertainties here range in our view, all the way between the two extremes, with the possibility that there are no long-term climatic effects no more excluded by what we know now than are the scenarios that predict months of subfreezing temperatures."

These observations are consistent with the findings in the recent National Academy of Sciences report. We believe the Academy report has been especially useful in highlighting the assumptions and the considerable uncertainties that dominate the calculations of atmospheric response to nuclear war. While other authors have mentioned these uncertainties, the Academy report has gone to considerable length to place them in a context which improves understanding of their impact.

We agree that considerable additional research needs to be done to better understand the effects of nuclear war on the atmosphere, and we support research as a means of advancing that objective. However, we do not expect that complete results will be rapidly achieved. As a consequence, we are faced with a high degree of uncertainty, which will persist for some time.

In view of the present and prospective uncertainties in these climatic predictions, we do not believe that it is possible at this time to draw competent conclusions on the biological consequences, beyond a general observation as suggested by the Academy report: if the climatic effect is severe, the impact on the surviving population and on the biosphere could be correspondingly severe.

With this appreciation of the importance of global climatic effects generally accepted within the defense community, I will discuss the "state-of-the-art" of the early global effects calculations. I then propose to use that discussion as a point of departure to discuss the direction which future research should take.

The models used in early global effects research were actually a series of calculations that started with assumed nuclear exchange scenarios and ended with a quantitative estimate of an average hemispheric temperature decrease. Since these phenomena are exceedingly complex and beyond our normal experience; estimates, approximations, and educated guesses were used to produce quantitative results.

To appreciate the significance of the predictions derived from these models, it is necessary to understand some of their features and limitations. Generally, there are three phases to the modeling problem: the initial production of smoke and dust; their injection, transport, and removal within the atmosphere; and the consequent climatic effects.

In the early models, the amount of smoke initially produced in any given scenario was probably the most uncertain parameter. This was because a large number of poorly-known variables were combined to determine the amount of smoke that could be produced from any single nuclear explosion. In reality, the same yield weapon could produce vastly different amounts of smoke over different target areas and under different meteorological conditions. Some of the factors that must be considered include thermal energy required for ignition of the various fuels associated with a particular target area, sustainability of such a fire, and atmospheric transmission and the terrain features that would determine the area receiving sufficient thermal energy from the fireball to cause ignition. Additional considerations are the type and quantity of combustible material potentially available for burning, the fraction that actually burns, and finally, the amount of smoke produced per unit mass of fuel burned. Every target is unique with respect to this set of characteristics, and a given target could change greatly depending on local weather, season, or even time of day.

Early modeling work did not attempt to analyze the individual targets or areas used for their various scenarios; rather, it made estimates of average or plausible values for all the parameters needed to satisfy the model. Although reasonable and consistent with the level of detail in the analysis, the procedure has the potential for large error in estimating these averages. In one case, a more detailed assessment of smoke production has recently been completed as a result of the ongoing U.S. Defense Department research in this area. Small and Bush's analysis of smoke produced as a result of hypothetical non-urban wildfires can be compared with the corresponding modeling assumption used in the TTAPS scenario (of Dr. Richard Turco, et al) (the abbreviation TTAPS comes from the first letters of the authors' last names). Bush and Small studied 3,500 uniquely located, but hypothetical targets, characterizing each according to monthly average weather, ignition area, fuel loading, fire spread, and smoke production. The results showed a significantly smaller smoke production—by a factor of over 30 in July to almost 300 in January—than comparable TTAPS results. An effort is underway to resolve this great difference.

In the early analyses, smoke was more important than dust in many cases, leading some to focus on fires rather than dust. Should smoke be systematically overestimated, especially in scenarios that emphasize dust production over smoke (such as attacks on silos using surface bursts), analytic results would be skewed.

Another illustration of a critical parameter subject to significant uncertainty is the total injected mass of submicron size dust, uncertain to a factor of roughly ten, based on our current knowledge. After smoke and dust are estimated, a model must then portray their injection into the atmosphere, removal processes, and transport both horizontally and vertically. Early one-dimensional models did not directly address these processes. (A one-dimensional treatment of atmospheric properties and processes considers only the vertical direction, with no latitudinal or longitudinal variation as exists in the real world. A one-dimensional model can only deal with horizontally averaged properties of the entire hemisphere.)

Of further significance, the land, the oceans, and the coastal interface regions cannot be treated in one-dimensional models. This is a critical deficiency because the ocean, which covers almost three-fourths of the earth's surface, has an enormous heat capacity compared to the land and will act to moderate temperature changes, especially near coastlines and large lakes. Early reports acknowledge this limitation and point out that these effects would reduce predicted temperature drops.

Because there is no horizontal (latitude and longitude) dependence in a one-dimensional model, the extent to which smoke and dust would be injected into the atmosphere over time is not realistic. Instead, the total smoke and dust estimated for a given scenario must be distributed uniformly over the hemisphere at the start of calculations. The most certain effect of all this is that the hemisphere average temperature drops very rapidly—much faster than it would in a more realistic three-dimensional model using the same input variables.

The one-dimensional model has other shortfalls and uncertainties. Recovery from the minimum temperatures must be accomplished through the gradual removal of smoke and dust. One must also assume that this removal rate is the same in a perturbed atmosphere as it is in the normal atmosphere. Most pollution removal depends on atmospheric circulation and precipitation. In an atmosphere with a very heavy burden of smoke and dust, the circulation and weather processes may be greatly altered. Some potential alterations could lead to much slower removal than normal; others to more rapid removal. Even in the normal atmosphere, removal of pollutants is a poorly understood process, let alone one that has endured a nuclear exchange.

This discussion of the deficiencies of a one-dimensional model is not meant as a criticism. A one-dimensional model is a valuable research tool and can provide some preliminary insights into the physical processes at work. The three-dimensional models needed to treat the problem more realistically are exceedingly complex and require very large computational resources. The U.S. Defense Department (DoD) and Department of Energy, in conjunction with the National Center for Atmospheric Research (NCAR) and other agencies, are pursuing the development of three-dimensional models to treat the atmospheric effects problem. The work is progressing, and the first results of this effort are now beginning to appear. Though modeling is preliminary and incomplete for any specific scenario, it does suggest that:

Substantial scavenging of smoke injected into the lower atmosphere from the continents of the Northern Hemisphere may occur as the smoke is being more widely dispersed over the hemisphere.

Lofting of smoke through solar heating could act to increase the lifetime of the remaining smoke and may reduce the sensitivity to height of injection.

For very large smoke injections, global scale spreading and cooling are more likely in summer than in winter.

Despite initial progress in the areas of smoke and dust injection, transport, and removal, many basic problems need to be solved. To make the model results more accurate, we must improve our understanding of the basic phenomena occurring at the micro, meso, and global scale.

One final problem should be mentioned. Dust and smoke have differing potential to affect the climate only because of their ability to absorb and scatter sunlight. The absorption and scattering coefficients of the various forms of smoke, dust, and other potential nuclear-produced pollutants must be known before any realistic predictions can be expected. Again, there is a large uncertainty, and what we do know about pollutants in the normal atmosphere may not be correct for the conditions in a significantly altered atmosphere. Also, the properties of "aged" pollutants are different from the properties of "fresh" pollutants.

From research results to date, we believe it is possible to draw some general conclusions which can guide our future work:

Importance of early time versus late time phenomenon.—Based on research to date, it seems clear, even while some project that global effects may persist for weeks or months, that the reality of global effects will be established upon the basis of phenomenon occuring within the first several hours to a day or so after the nuclear explosions. It is within this period of time that many of the critical processes will have made their contribution: target fuel loading, fuel bed redistribution (rubblization), ignition, combustion, smoke emission, fire spread and development, plume formation, interaction between multiple bursts, early time scavenging, dispersion, and mesoscale transport. Only when we have refined these parameters, based upon theory and experiment, will we have reasonable inputs upon which the global scale circulation models can make predictions of the global effects on the climate.

Importance of a deliberate approach.—The physical processes implied in the global effects phenomenon far exceed that of our documented experience; thus, our approach to reducing the uncertainties and filling the gaps in our knowledge should proceed at a deliberate pace. We believe that progress in theoretical understanding of the processes, tested against laboratory scale experiments, should precede the design and conduct of large scale experiments. Large scale experiments performed without adequate input understanding can easily lead to masses of expensive data of doubtful value. This is not to say that we should not take advantage of targets of opportunity, such as large scale prescribed fires, but rather we should put our emphasis on carefully designed small scale experiments with well defined, theoretically sound objectives. Finally, no practical experiment will replicate the events which might trigger the global climate effects, thus it is essential that our theory be on a firm foundation, backed by experimental data based upon experience at several scales, to provide confidence in our ability to extrapolate to the scales of interest.

Importance of realistic interactive global modeling—Ultimately, only the global atmospheric models, given the best available inputs, will be able to predict, on a global scale, what the climate effects might be. These should be carefully developed to insure that they realistically replicate the various processes and are fully interactive with the smoke and dust pollutants. It will be important that the outputs of the models be specific in terms of climate description, for example providing temperature, precipitation, and light time histories as a function of geographic location rather than hemispheric average changes. Considerable advances have been made in the last two years in atmospheric modeling, with three-dimensional interactive models now operating at reasonable resolution. More work will be required to increase our confidence that the models will continue to replicate the atmosphere even under highly perturbed conditions.

Thus far, the physical processes of global climate effects have been discussed rather than the implication of the effects on people, the environment, and ecosystems. There is a need for some continuing dialogue with the life sciences to identify the appropriate descriptions of the climatic changes to support follow-on analysis of the implications of global climate effects on people, the environment, and ecosystems. Beyond that, given the range of uncertainty and coarseness in the present climate predictions, from relatively benign (in the context of a nuclear exchange) to months of subfreezing temperatures, it would seem that any conclusions drawn concerning agricultural, biological, or human consequences of long-term climatic changes would be speculative and necessarily qualified by the rather large uncertainties in nuclear war scenarios and atmospheric consequences.

Given this general direction for our future efforts, how do we plan to proceed? The U.S. government's global effects research program is being conducted under the auspices of an Interagency Research Program chaired by the Office of Science and Technology Policy with participation by the Department of Commerce, Department of Defense, Department of Energy, and the National Science Foundation. The Interagency Research Program encompasses all of the scientific research required to improve our understanding of global effects including the life sciences when appropriate. As was the case in prior years, work will be supported in the best qualified research institutions including the national laboratories, colleges and universities, private industry, and others as appropriate.

While the interagency group is responsible for coordination of the entire program, program definition and funding is the responsibility of the individual participating agencies. For fiscal 1986 the interagency program is as follows:

Department of Defense	$2,500,000
Department of Energy	2,500,000
National Science Foundation	500,000
Total	5,500,000

The Defense Department global effects program is divided into six categories, as follows, with the planned fiscal 1986 funding levels:

Fuel bed database compilation	$100,000
Smoke and dust source terms	500,000
Chemistry and microphysics	500,000
Plume dynamics and cloud physics	600,000

Mesoscale and global modeling	500,000
Overall analysis and applications	300,000
Total	2,500,000

Chairman **Goldwater**. Thank you very much, Doctor.

I think we will have the other witnesses testify and then we will address questions to all of you. It has been a very, very interesting presentation.

Would the members of the committee rather do it that way or interrogate each witness?

Thank you, Doctor.

I will ask Dr. Harwell, from the Center for Environmental Research at Cornell University, to present his case.

Welcome to the committee.

STATEMENT OF MARK HARWELL, ECOSYSTEMS RESEARCH CENTER, CORNELL UNIVERSITY

Dr. **Harwell**. Thank you.

I, too, want to thank you for the opportunity to make this discussion before this committee. I would like to say that I am representing not just myself and my own studies, but consider myself as spokesperson for the Scope project which Dr. Gillespie referred to. Let me briefly tell you about this project.

Scope is a standing committee on the environment, part of the International Council of Scientific Unions which is basically, as you probably know, the national academy of sciences and royal societies of various countries around the world.

They commissioned a study 3 or 4 years ago to look at the global consequences of nuclear war, commissioned a study before the idea of nuclear winter was out in the general public or of interest in the scientific community.

What has emerged is a twofold study which has led to two volumes that were presented publicly about 2 weeks ago to the Scope general assembly.

The first volume, which I have here, is on the physical and atmospheric effects of nuclear war and represents the state-of-the-science assessment of the current understanding and uncertainties on those issues. (See p. 42.)

The second volume, which I had primary responsibility for, is on the ecological and agricultural effects and the human consequences. (See p. 55.)

Altogether, these two studies involved something like 300 scientists from over 30 countries around the world trying to assess, based on existing data and existing models, what the consequences of a nuclear war would be.

Now, let me say, first, with respect to the physical and atmospheric side, I am not an atmospheric scientist. However, I am familiar with the volume and can answer, I think, the questions that pertain to that.

Much of what Dr. Gillespie has discussed is reflected in this volume. Let me give a couple of brief comments.

One is that many of the uncertainties that previously were considered important have been resolved. On the other hand, other issues have come to the forefront and are yet to be analyzed.

In looking at the biological consequences of nuclear war, we were aware on the biological side, of course, of the uncertainties that exist on the climatic consequences and on other aspects of the direct effects of nuclear war. We wanted not to tie ourselves to any specific nuclear war scenario.

Likewise, we did not want to tie ourselves to any specific climatic projections. So, rather than do that, we looked at what the vulnerabilities of our biological systems would be to the types of physical stresses that were projected as possible to occur.

We felt by looking at vulnerabilities, we could then characterize whether or not the potential climatic changes and other effects that the physical scientists were projecting might lead to significant ecological, agricultural, and human consequences.

The conclusion we came to—I will give them to you first and then tell you how we got there—is that the vulnerability of biological systems, especially agricultural production and distribution systems, is so great, so sensitive to the sorts of perturbations we are talking about that many of the uncertainties that Dr. Gillespie was referring to are unimportant.

The sort of climatic perturbations at the low ends of the ranges are more than sufficient to lead to catastrophic consequences, catastrophic to the degree that we now estimate that the indirect effects of nuclear war could be more consequential than the direct effects.

Now, as an example of that, a number of studies have been done on the direct effects of nuclear war, and even looking at severe sorts of scenarios, the range of several hundred million casualties is possible, whereas our analysis shows that the indirect effects potentially could be fatalities in the range of 1 to 4 billion people worldwide.

Further, our estimates are that the primary mechanism for human facilities would not be the blast wave, would not be thermal radiation and burns, would not be ionizing radiation, but, in fact, would be mass starvation.

Now, to get to this point, we considered a number of physical stresses on the environment. We concentrated particularly on climatic aspects, but also looked at the effects of local and global fallout, ultraviolet light, and air pollutants and other stresses.

Let me address the last few before getting to the climatic effects.

With respect to ionizing radiation, global fallout is not considered to be a significant human health effect, not compared to what the other consequences of nuclear war would be.

However, what is called local fallout, fallout that occurs within the first 24 or 48 hours after a surface detonation, these can certainly lead to radiation far exceeding the legal level for humans. In the Scope study with one scenario, in the range of 5 to 10 percent of the land area of the United States could be covered with levels of radiation exceeding lethal amounts.

There are uncertainties on that that could make that smaller or greater by a factor of three or four.

With respect to ultraviolet light effects, this could result from potential impact on the ozone layer. The current assessment is that these would not lead to catastrophic effects compared to the climatic effects.

However, some recent studies have shown that there is a potential for the smoke particles generated by fires to interact with the ozone layer. If they reach the stratosphere, that considerably further degrades the ozone, current assessment would indicate.

With respect to climatic analysis, we considered the effects of reduced temperature, reduced sunlight, and reduced precipitation on ecological and agricultural systems, and we divided these climatic effects into two main categories: One, which we call acute, relates to the sort of extreme temperature decreases that have been predicted for nuclear winter, in the order of tens of degrees Centigrade decreases for days or weeks.

Second, we also considered the potential chronic phase decrease in climatic conditions. These are in the range of a few degrees Centigrade, between 1 and 5 or even 10 degrees Centigrade, that persist well beyond the immediate time period, perhaps for several years.

Now, on the ecological side, I don't want to spend much time on that, but let me just say that our studies show that virtually every environmental issue of concern today would be a direct consequence of a large-scale nuclear war, be it habitat destruction, species distinction, air pollution, you name it; it would all be a part of the consequences of nuclear war, only on a spatial extent and an intensity far more severe than any precedent.

Therefore, that the consequences on ecological systems would be very severe, would likely have very long-term effects, and prospects for recovery of different systems are uncertain.

The key issue is what is the importance of that with respect to human population. We looked at the potential of what would be called the carrying capacity of ecological systems for humans.

We calculated that even perfectly healthy ecological systems could support less than 1 percent of the current world human population. Even if there were no ecological disturbances at all following a nuclear war, it is clear if there were disruption in the agricultural productivity that humans can't just rely on the land to support their populations.

We looked at agricultural systems as one type of ecological system and found they are by far the most vulnerable to the sorts of perturbations that we were considering.

We looked at a number of lines of evidence to come to an assessment of the vulnerability of ecological systems because there is no single bit of evidence, no experimental evidence that could be drawn upon. We are talking about something on a scale that has never happened and no one before thought was experimentally worth doing.

So, we drew upon historical episodes that might be used as analogues. We conducted a number of statistical analyses that would look at multiple events and multiple years to get relationships between temperature decreases and crop productivity.

We looked at considerable laboratory data on physiological experiments: as an example, the responses of plant growth to temperature and light regimes.

We conducted a number of computer simulation models on crop productivity, and I will talk a bit more about that in a minute.

Then we relied on expert judgment to try to come up with an assessment of what these consequences would be. The focus is on grain crops because these constitute the most important component of the human diet, and that probably would be even more so following a nuclear war.

We found that the temperature decreases potential from the aftermath of a nuclear war were the most important variable. There are a number of different mechanisms by which temperature and also light reductions could affect crop productivity.

One of these is the potential for brief periods of freezing or chilling events during the growing season. These short duration episodes would probably be the most important part of the acute period following a nuclear war.

Other factors that could lead to loss of crops, not just reductions in productivity, but actual loss of crops, relate to an insufficient growing season length, insufficient amount of what is called thermal time over the growing season, and insufficient number of cumulative hours of sunlight.

All of these act in a nonlinear way and can lead to total loss of crops. There are other factors that can lead to reductions in yield; that is when you might actually get some crops, but their yields would be reduced. These relate to decreases in light, temperature, and especially precipitation.

The conclusion in looking at these various mechanisms by which climatic reductions could affect crop productivity was that there is a clear possibility that in the Northern Hemisphere in the initial growing season following a nuclear war, essentially all agricultural production would be lost in response to an acute type of climatic condition.

Further, we felt that in the longer time period, extended into several growing seasons thereafter, the chronic climatic and other conditions could also lead to severe disruption in agricultural production.

Now, one of the interesting things we found was that even if there were no climatic disturbances whatsoever, crop productivity could be substantially decreased in response to loss of energy subsidies for agriculture; for example, fuel, fertilizer, pesticides, machinery, and so on. Disruption in these energy supplies, which would likely occur in combatant and noncombatant countries alike, could reduce crop yields by 25 to 50 percent.

Similarly, reductions in precipitation and sunlight would significantly reduce productivity, as well as certain indirect effects such as increased pest outbreaks in response to ecological disturbances.

We came to the conclusion, then, that there is a potential for the essential loss of Northern Hemisphere agricultural production for at least one growing season.

Then the next point was how that translates into effects on the human population. Again, we looked at the vulnerability. Rather than looking at a specific agricultural production level, we look at vulnerability of the human population globally to disruption in food production and imports.

We specifically looked at 15 countries in considerable detail and another 120 countries that we had fewer data on. We focused on the food stores that are in countries, the dietary minimum caloric requirement for humans to consume in order to stay alive, and considered such things as disruption in food imports and fuel imports, and so on.

One key point is that while we treated it as if there were no imports of food across country boundaries, within a country we treated it as if there was perfect distribution of food; that is, that everybody had an equal share of food, no more than they minimally needed to be kept alive. If it turned out there wasn't enough food to support the entire population, then those people who were going to die eventually would not consume any food from the beginning.

Clearly these assumptions overestimate the number of people that could be kept alive. The outcome of these analyses was that the vast majority of the people in the world live in countries for which there is far less than 1 year's supply of food. Typically, 3 to 6 months is more common among various countries.

This value changes or differs over the year, and if the war were to occur at a point where food stores were at a minimum, such as just before harvest time, then the duration of food is much, much less.

There are a few countries for which there are multiple years of food supply available, specifically, Canada, United States, and Australia. But globally food stores alone could keep alive only about 1½ billion people for 1 year based on a median level of food stores.

One other interesting aspect of the analysis was the effect of disruption in food imports. Even if you assumed there were no decrease in food productivity, just cutting off imports to a country like Japan would mean that half of the population could not be maintained by their current production, even if they could maintain 100 percent of current production. Clearly there are many reasons why agricultural production in a country like Japan would be decreased.

The conclusion from these analyses is that there are clearly potentials for more fatalities from indirect effect than from direct effects.

A key point is that the risk of nuclear war is in effect exported to noncombatant countries, and that you are at least as much at risk from nuclear war if you live in a country like India than if you live in the United States. Indeed, our calculations show that in a large-scale nuclear war involving only the United States and Soviet Union, more people would die in India than in both those two countries combined.

Similarly, more people would die in Africa with no bombs on their land whatsoever than would die in Europe.

The other point is, I again emphasize, that only the lower ranges of estimates of the climatic effects are all that is required. You don't need tens of degrees C to lead to these consequences, but a few degrees is adequate. Further, there would be extreme indirect effects even if there were no climatic consequences whatsoever.

Thank you.

[The prepared statement of Dr. Harwell follows:]

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Nuclear Famine: The Indirect Effects of Nuclear War

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Introduction

Over a two-year period, the SCOPE-ENUWAR project involved the participation of about 100 physical and atmospheric scientists and an additional 200 agricultural and ecological scientists from more than 30 countries around the world in a unique undertaking to assess the global consequences of nuclear war. The atmospheric scientists convened in a series of workshops, taking stock of their on-going research and identifying the next issues to be examined with their computer models. From this emerged the state-of-the-art characterization of the projected nuclear-war induced disturbances in the global atmosphere, with specified uncertainties and research needs (Pittock et al., 1985). We on the biological side did not have the luxury of existing funded laboratory and modelling research projects on the consequences of nuclear war; instead, our mission was to inspect the current information, models, and understanding of how biological systems respond to stress. From these data and models, developed for reasons far removed from considerations of nuclear war, we synthesized a portrait of the global world after nuclear war (Harwell and Hutchinson, 1985). The focus was on human population impacts mediated by disruptions in ecological, agricultural, and other life-support systems.

The consensus that developed was stark: that the *indirect* effects of a large-scale nuclear war would probably be far more consequential than the *direct* effects, and that the primary mechanism for human fatalities would likely not be from blast effects, not from thermal radiation burns, not from ionizing radiation, but, rather, could be from *mass starvation*. Whereas the direct effects of such a nuclear war could result in several hundred million human fatalities according to several studies (e.g., WHO, 1984; Ambio, 1982), the indirect effects could lead to the loss of one to four *billion* humans.

This conclusion derives from considerations of the *vulnerabilities* of ecological and agricultural systems to the types of disturbances potentially associated with the occurrence of a large-scale nuclear war. Thus, the biological analyses were not linked to any specific nuclear war scenario or to any single specific projection of alterations in the physical environment. This disassociation with particular scenarios was sought to avoid being limited by the current uncertainties of the physical estimates. Many of these uncertainties are irreducible, such as the specific details of an actual nuclear war, details that would only become certain as the war itself developed. Other uncertainties can be reduced by further investigations, such as the processes controlling smoke emissions and scavenging in the atmosphere. However, we cannot delay making biological and, especially, human impact assessments until such issues become fully resolved. By examining the vulnerabilities of biological systems to *classes* of perturbations, our results can be applied to a full range of possible physical outcomes of nuclear war. Moreover, since the biological systems were found to be so sensitive to nuclear war-induced stresses, consensus was reached on biological responses and human impacts with perhaps less uncertainty than remains for the physical estimates.

The categories of potential physical nuclear war-induced stresses that were examined are listed in Table 1. There was an emphasis on the effects from climatic disturbances, discussed in detail below, but other mechanisms for indirect effects were examined, including in particular effects from ionizing radiation and from increased levels of ultraviolet light. The climatic stresses were categorized with respect to the types of biological issues of importance. Specifically, an acute phase of climatic disturbance characterized by an abrupt onset of lowered temperatures and associated reductions in sunlight was identified as representing the potential environment in the first few days to weeks after the nuclear war. No single temperature/light decline was assumed; rather, the vulnerability of biological systems to brief episodes of chilling or freezing temperatures was examined. Similarly, for chronic-phase climatic disturbances, the vulnerability of biological systems to a few degrees' (Celsius) reduction in average temperatures persisting over the growing season, accompanied by 5-20% reductions in sunlight and possible decreases in precipitation, was evaluated.

In order to make these evaluations, no single set of experimental data was available; instead, a number of lines of reasoning was drawn upon to exploit the full range of relevant information (Table 2). The historical approach involved examination of specific episodes of environmental stresses and responses which have actually been experienced. For instance, incidents of freezing events in sub-tropical regions (e.g., Florida and southern Texas) were examined for their effects on fish populations, fruit trees, and other biological systems. Statistical analyses were done on data representing multiple years and multiple locations, seeking the relationships among the physical environment and biological systems. For instance, the relationship between the average air temperature experienced over growing seasons and the length of the frost-free period (a measure of growing season duration) was characterized statistically. Laboratory data were evaluated for physiological-level information, such as the growth rates of crop plants under laboratory conditions of different levels of temperature, light, moisture availability, and air pollutant exposures. Computer simulation models of ecological and agricultural systems were used for assessing the effects of chronic alterations in climate on crop yields and ecosystem productivity. And the judgment of scientists with expertise in specific agricultural and ecological systems was relied upon to identify and evaluate available data and models and to extrapolate beyond the current experimental and historical records to obtain the best estimates of biological system responses to nuclear war. For the most part, the physiological-level data and expert judgment were used to evaluate acute vulnerabilities, and the less extreme perturbations associated with chronic-phase conditions were more suited to historical, statistical, and computer simulation analyses.

These approaches were applied to each major biome type (Table 3 and Figure 1), covering freshwater, marine, and terrestrial ecosystems from the arctic to the Southern Ocean and including the main grain crops in the northern temperate, tropical, and southern temperate regions of Earth. A number of international conferences were convened, each specifically addressing particular system types: northern temperate ecosystems were addressed at Toronto, Canada; northern temperate agriculture at Essex, U.K.; tropical ecological and agricultural systems at Caracas, Venezuela; Southern Hemisphere extra-tropical ecological and agricultural systems at Melbourne, Australia; and general biological responses to radiation at Paris, France. Other conferences dealing with more generic biological issues were held in Stockholm, Sweden; New Delhi, India; Leningrad, U.S.S.R; and Essex, U.K. A special conference on the experiences and extrapolations from the Japanese nuclear bombings was convened in Hiroshima and Tokyo, Japan. At each conference, as broad a consensus as possible was sought among the experts, with identification of unresolved issues and research needs. Many of the latter were addressed within the ENUWAR project itself, with specific statistical and computer simulation analyses initiated. We used the reports of the various conferences, the results of the commissioned analyses, and additional studies conducted by the ENUWAR teams at Cornell University and the University of Toronto as the bases for writing the 550-page Volume II of the ENUWAR report. This was subjected to an extensive review process, during which we assured faithful representation of the consensus of the participants of the conferences; the completed book provides the technical basis for the conclusions presented here.

Ecosystem Vulnerabilities

The vulnerabilities of *ecological systems* were found to differ among ecosystems, types of disturbances, and time of year. For example, temperate forests were found to be most sensitive to acute, extreme temperature changes occurring during the spring or summer, whereas marine ecosystems were quite tolerant to changes in air temperatures. However, marine ecosystems are very vulnerable to disruptions in the levels of incident sunlight, with acute reductions in insolation resulting in collapse of phytoplankton and perhaps zooplankton populations on a large scale. Grassland ecosystems and the wheat-growing areas of Australia were assessed to be most vulnerable to chronic disturbances in precipitation, during the summer in the case of African grasslands and during the winter in the case of Australian wheat.

These types of conclusions were based primarily on the understanding of plant responses to light, temperature, and moisture levels; by contrast, animal responses, especially with respect to propagation of effects from one species to another through species-species interactions, were considered to be more speculative and probably never fully predictable. It is clear that inadequate data bases and simulation model resources exist for precise characterization of ecosystem responses, particularly to the less extreme range of physical disturbances. Nevertheless, the various approaches outlined above suggest the cross-systems vulnerability estimates provided in Table 4.

Other analyses addressed the prospects for recovery for various ecosystems and the processes by which recovery could be effected. The consensus is that nuclear war-induced disturbances to the environment would include *virtually every environmental problem* of concern today -- be it habitat destruction, species extinction, air pollutants, toxic chemicals, acid precipitation, ozone depletion -- only on a scale of totally unprecedented extent and intensity. Precisely what the full ecological ramifications of such stresses would be and the specific pathways that subsequent recovery would follow are urgently in need of a concerted research effort in the general field of stress ecology. Other considerations, however, show clearly that even absent any disturbance to ecosystems, these natural systems could support only a very small fraction, on the order of 1% or less, of the current human population on Earth. The reason for this is that there is simply not the base of utilizable energy sufficient to maintain 5 billion people if we did not have agricultural and other human-controlled systems to rely upon. Thus, the carrying capacity of natural ecosystems is greatly exceeded by the current human population, and disruptions in human support systems that forced humans to rely substantially on natural systems for sustenance would necessarily lead to reductions in the human population. This fact provides the overriding incentive to examine the vulnerability of agricultural and food distribution systems to disruptions following a nuclear war.

Agricultural Vulnerabilities

An examination of the vulnerabilities of *agricultural systems* clearly showed that these systems are the most sensitive of any biological systems to changes in climatic conditions. There are several mechanisms by which climatic alterations translate into reductions or loss of crop yields. For most agricultural crops, temperature is the critical variable, although many are also sensitive to changes in precipitation and others can be limited by insufficient sunlight. Our studies focused on grain crops because these contribute the majority of the caloric inputs into the human diet on the global scale and because these crops are more effectively stored than most other food crops (e.g., fruits), a factor that could be critical in the aftermath of a nuclear war. Considering first the effects of temperature on grain yields, a number of factors are important:

1.) brief episodes of chilling or freezing temperatures - The occurrence of even short-duration events of freezing temperatures within the growing season leads to loss of grain yields, as demonstrated in laboratory experiments and in the historical record; for example, in 1816 ('the year without a summer') a series of frosts occurred during June through September, resulting in the loss of grain crops in the northeastern United States, eastern Canada, and western Europe. The occurrence of such episodes following a nuclear war could be expected to happen during the acute period, when average temperatures might be reduced by tens of degrees C for days to weeks. Because of cloud patchiness in the early smoke cloud development period, it could be expected that even greater temperature reductions could occur for brief periods of time. Furthermore, during the chronic period extending into growing seasons one or more years after the nuclear war, average temperature reductions of relatively small amounts (in the range of 1-5°C) would be associated with episodes of chilling or freezing events. The historical record indicates that years with extreme low temperatures during the growing season (e.g., 1816) had average temperature reductions of less than 1°C, which nonetheless caused large crop losses.

2.) insufficient growing season length - Associated with the average reduction in temperatures over the spring-summer months, such as expected during a chronic post-nuclear war period, would be a shortening of the length of the growing season, with delay in the occurrence of the last day of freezing temperatures in the spring and an early onset of freezing temperatures in the fall. Several lines of evidence indicate that in the Northern Hemisphere continental regions of the mid-latitudes (i.e., the main grain producing areas) on average a 1°C reduction in average temperature correlates to a 10 day reduction in the growing season length. As an example of this relationship, Figure 2 shows the average temperatures and growing season lengths for several locations in the United States over a several year period. The importance of this phenomenon is shown when a growing season is shorter than the growing season requirements of the crop in order for it to reach maturity and produce a yield. More on this aspect will be discussed below.

3.) insufficient growing-degree days - The term *thermal time* is used as a measure of the number of hours during the growing season that air temperatures exceed a specified base level by various amounts and is calculated by multiplying the duration of exceeding the base level times the increment of temperature above that level. For example, for a base level of 10°C, two days with a temperature of 20°C would have the same thermal time as one day with a temperature of 30°C. As with growing season requirements, each variety of crop plant has a particular requirement for a total amount of thermal time, measured as growing degree-days, that is needed in order for the crop to mature. Below the threshold for thermal time, maturity does not occur and grain yields are lost. Again in the chronic period after a nuclear war, the thermal times may be too low for grain production.

4.) insufficient integrated sunlight time - A similar situation exists for the numbers of hours during the growing season during which sunlight levels exceed a certain amount. Simulations of Canadian wheat production showed that reductions in insolation by about 20% over the growing season led to total loss of yield because of not exceeding the required threshold.

Thus far we have looked at mechanisms by which temperature and light reductions would lead to *total* loss of crops for the growing season. In addition, the altered climate could be sufficiently benign so that some productivity remained possible, but the yields could be substantially reduced from current levels. The mechanisms are:

5.) reduced productivity in response to physical environment - Laboratory data can show those circumstances in which the thresholds of stress that would eliminate production are not exceeded, but less-than-optimal conditions reduce yields. These can result from reduced temperatures, reduced light levels, and reduced precipitation levels. As an example of the latter, the historical record and computer simulations indicated that wheat yields in Australia are essentially linearly reduced with reductions in rainfall; i.e., a 25% reduction in precipitation could be expected to result in at least a 25% reduction in yields.

6.) disruptions in energy inputs to agriculture - The considerations to this point have focused on the yields possible assuming continued high levels of energy inputs to agriculture, e.g., inputs of fertilizers, pesticides, herbicides, fuel for tilling and harvesting, machinery, etc. However, in the aftermath of a large-scale nuclear war, the availability of these subsidies to agriculture, in combatant countries and in non-combatant countries that rely on others for energy and commodity imports, would be severely disrupted or eliminated. Current yields of grains are heavily dependent on such energy subsidies, as demonstrated by Figure 3, showing the tremendous increase in yields over the last four decades which is largely in response to increases in energy subsidies. Assessments indicate that *even in the absence of any climatic disturbances* disruptions in agricultural subsidies could lead to reductions in crop production by up to 50%.

The Agriculture Canada model of spring wheat production illustrates the potential effects of chronic climatic alterations on crop production following a nuclear war (Figure 4). A map of the wheat-producing provinces of western Canada shows the current boundaries for wheat production and the boundaries associated with a reduction in temperatures over the growing season on average by 1°C, 2°C, 3°C, and 5°C. The 1°C reduction in average temperature results in a decrease in the potential growing area by a relatively small amount, but a 2°C reduction in average temperature eliminates the majority of the growing areas; a 3°C reduction would result in the *complete elimination* of any wheat in Canada. This effect follows both from the reduction in the growing season length and in the insufficient levels of thermal time. Similar results were found for all other crops simulated, including much warmer climate crops such as soybeans (for which only a 4-6°C reduction in average temperature would eliminate yields in the southern United States).

Rice was especially evaluated because of its large share of the human diet on a world-wide basis and because a disproportionate number of immediate post-nuclear war survivors would live in tropical and sub-tropical regions. We found that rice is the most sensitive of grains to temperature reductions, and that rice yields can be eliminated even in the absence of frost. In fact, at certain times during the growing season, temperatures below 15°C lasting for only one or two nights would be adequate not to kill the rice plants but to preclude the formation and maturation of the rice grains. The historical evidence of rice production in Japan adds considerable support to the conclusion of extreme temperature sensitivity for rice; for example, when average summer temperatures are reduced in Japan by 1-2°C, crop failure occurs.

From these and many other analyses and considerations, the strong consensus that emerged among the agricultural scientists associated with ENUWAR is that *the acute phase of climatic disturbances could eliminate grain production in the Northern Hemisphere* following a large-scale nuclear war that occurred in the spring or summer and perhaps at other times of the year. Further, *the chronic phase climatic conditions could also be expected to result in severe reductions or total elimination of yields of Northern Hemisphere grain crops*, and Southern Hemisphere crops could also be adversely affected. Superimposed on these responses would be severe reductions in yields in response to loss of energy subsidies, reductions in precipitation, and loss of arable land in combatant countries because of radioactive fallout. Additional yield reductions could follow enhanced levels of ultraviolet light and air pollutants. Clearly, for the first time there are multiple mechanisms by which food production could be disrupted on at least a hemispheric scale. A critical point in this is that these disruptions would occur at climatic disturbances *at the very low end* of the range of climatic changes projected likely to occur; thus, many of the uncertainties associated with climatic projections are irrelevant to the impacts on food production, since the levels of temperature changes under discussion (e.g., tens of degrees C average decreases in air temperatures in the grain-producing areas of the Northern Hemisphere for a spring-summer nuclear war) well exceed the thresholds necessary for elimination of grain yields.

Vulnerability to Disruptions in Food Availability

These conclusions of the potential for massive disruptions in food production must obviously be examined to assess the *potential impact on humans*. Since we cannot predict precisely how much food production would be affected, because of the climatic and nuclear war uncertainties discussed previously, we again focused on the *vulnerability* of the human population to disruption in food production for one or more years. The key issue here is the amount and duration of *food stores* as distributed around the world.

In order to make this assessment, we examined data from the FAO and other sources for 15 countries for which we acquired extensive data on the quantities of grains stored, the current and estimated immediate post-nuclear war population levels, the age structure of the population, and the minimal caloric requirements that humans require for subsistence. These 15 countries include about 65% of the human population and were selected to represent the range of situations in the world, including highly industrialized nations, likely combatants, underdeveloped countries, Northern and Southern Hemisphere locations, tropics and temperate regions, and various density of populations. Included in the analyses are the United States, the U.S.S.R., China, India, Australia, Japan, Costa Rica, Nigeria, and others. In addition, we acquired less extensive data to analyze the situation in 120 other countries, representing almost the entire world's population. Some simplifying assumptions were required: a.) grains were assumed to be fed only to humans, diverting the large quantities that currently are designated for animal feed; b.) the diet was assumed to change to primary reliance on grains as opposed to current patterns of consumption; c.) no imports or exports of grains or energy supplies were assumed to occur in the aftermath of a large-scale nuclear war; d.) grain stores in combatant countries were assumed to be destroyed approximately in proportion to the loss of human life from direct effects of nuclear detonations; and e.) within each country, food distribution was assumed to work perfectly, such that each person received exactly the amount minimally needed for survival; further, if it was found that there would be insufficient food to keep the full population in the country alive for one year, then the maximum numbers of people that could be maintained were assumed to consume all the food stores, and no food was assumed to be eaten at all by those eventually doomed to starvation. Clearly, the last set of assumptions provides a very considerable *overestimate* of the number of people that the food stores would actually keep alive and provides the physically limited upper value for population maintenance. The issues of societal disruption and other factors that could lead to a less-than-perfect distribution of food in the aftermath of a nuclear war were not analyzed, but these require a concerted scientific study.

The picture that emerged from these food calculations follows:

1.) For a very few countries, those that are the major grain-exporters such as the United States, Canada, and Australia, the grain stores are in principle sufficient to keep the surviving population alive for a few years. Again, other factors might well change this conclusion if food were not appropriately distributed, and long-term sole reliance on such grains could lead to nutrient deficiencies that were not calculated in our analyses. Also, these would also likely be combatant countries, so that the direct effects would be extensive.

2.) For the rest of the world, including the vast majority of the countries and of the human population, there is less than one years' food supply typically available during the year; for most countries the food duration is on the order of half a year or less. Further, if the war were to occur prior to harvest (i.e., when food supplies were at their minimum levels), most of the stores would last only a matter of weeks to a few months.

3.) *Consequently, if food production were disrupted for one or more growing seasons, there simply would be not enough food to keep most of the survivors alive. Starvation, and the diseases and societal disruptions associated with starvation, would account for global declines in the human population.*

An indication of the extreme vulnerability of the Earth's human population to sole reliance on food stores is seen in Figures 5a-c. The first shows the current population as distributed within latitude bands and the expected population distribution to occur after a large-scale nuclear war (based on other analyses involving a severe-case impact on cities). Figure 5b shows the current population in comparison with how many people could be kept alive for one year under the assumptions discussed above if food stores were at their median level at the time of the nuclear war; Figure 5c shows the same, but for food stores at their minimum levels. These benchmark calculations make crystal clear the extent on a global scale of human vulnerabilities.

One other analysis is also noteworthy: even if there were *no* impacts on food production at all but only direct food and energy imports were disrupted, many countries would still be severely affected. Japan is the most striking case in point (Figure 6), where cessation in food imports would result in the loss of half the total population in Japan, even if 100% of current agricultural productivity could be maintained and if no nuclear detonations occurred on the country. In the much more likely situation of food production impacts, such as from energy input disruptions or from mild climatic alterations, then 25% of current grain production could keep only about 15% of the population alive in Japan.

Conclusions

The conclusion from these analyses is that *the indirect effects of a nuclear war, especially as mediated by disruption in food availability, could be much more extensive than the direct effects.* Further, this risk is especially severe for the non-combatant countries of Earth, for the 4 billion or so humans expected to survive the immediate period of a nuclear war relatively physically unharmed. Thus, a fundamentally different picture of the post-nuclear war world results, where a large-scale nuclear war between the United States and the Soviet Union would probably result in more eventual fatalities in India than in the U.S. and the U.S.S.R. combined, and more people would die on the African continent than in all of Europe. Rather than reflecting images of Hiroshima and Nagasaki, a modern nuclear war would, for most of the people of the world, much more resemble current images of Ethiopia and the Sudan.

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Table 1

NUCLEAR WAR-INDUCED STRESSES EXAMINED

- Climatic

    - Acute
        - temperature - episodes of chilling or freezing
        - light - episodes of 1-10% normal insolation

    - Chronic
        - temperature - average decreases of 1°, 3°, 5°, 7°, 10° C below normal over growing season
        - light - associated reductions in insolation by 5-20%
        - precipitation - reductions by 25-50%

- Radiation

    - local fallout
    - global fallout
    - focus on external gamma doses

- Other stresses

    - fire
    - UV-B
    - atmospheric pollutants

Table 2

ANALYTICAL APPROACHES

- historical analogs
- statistical analyses
- laboratory physiological studies
- simulation models
- expert judgment

Table 3

BIOME APPROACH

- Northern Hemisphere terrestrial ecosystems
    - arctic and boreal
    - deciduous forests
    - coniferous forests
    - grasslands
    - arid and semi-arid

- Northern Hemisphere aquatic ecosystems
    - freshwater
    - marine
    - estuarine

- Tropical ecosystems
    - evergreen rainforests
    - deciduous forests
    - montane-cloud forests
    - alpine
    - grasslands and savannahs
    - mangroves

- Southern Hemisphere extra-tropical ecosystems
    - Australian ecosystems
    - New Zealand ecosystems
    - Southern Ocean and Antarctica

Table 4

SUMMARY OF CONSEQUENCES FOR ECOLOGICAL SYSTEMS[a]

SYSTEM TYPE	STRESS/RESPONSES temp.	light	ppt.	rad.	UV-B	air pollutants	fire
agriculture	••••	•	•••	••	•	••	•
tundra/alpine	◆ ◊	• ◊	• ◦	• ◦	• ◦	• ◦	• ◦
boreal forests	•• ◦	• ◦	• ◦	•• ◦	• ◦	• ◦	• ◦
temperate forests							
deciduous	•• ◦	• ◦	•• ◦	•• ◦	• ◦	•• ◦	•• ◦
coniferous	•• ◦	• ◦	•• ◦	••• ◦	• ◦	• ◦	•• ◦
tropical forests	••• ◦◦◦	• ◦	•• ◦◦	• ◦	•• ◦◦	• ◦	•• ◦◦
grasslands	•• ◦	• ◦	•• ◦	• ◦	• ◦	• ◦	•• ◦
lakes and streams	•• ◦	•• ◦	•• ◦	• ◦	•• ◦◦	• ◦	◆ ◊
estuaries	•• ◦	••• ◦◦	• ◦	• ◦	•• ◦	•• ◦	◆ ◊
marine	◆ ◊	••• ◦◦	◆ ◊	◆ ◊	•• ◦◦	◆ ◊	◆ ◊

Table 4 continued

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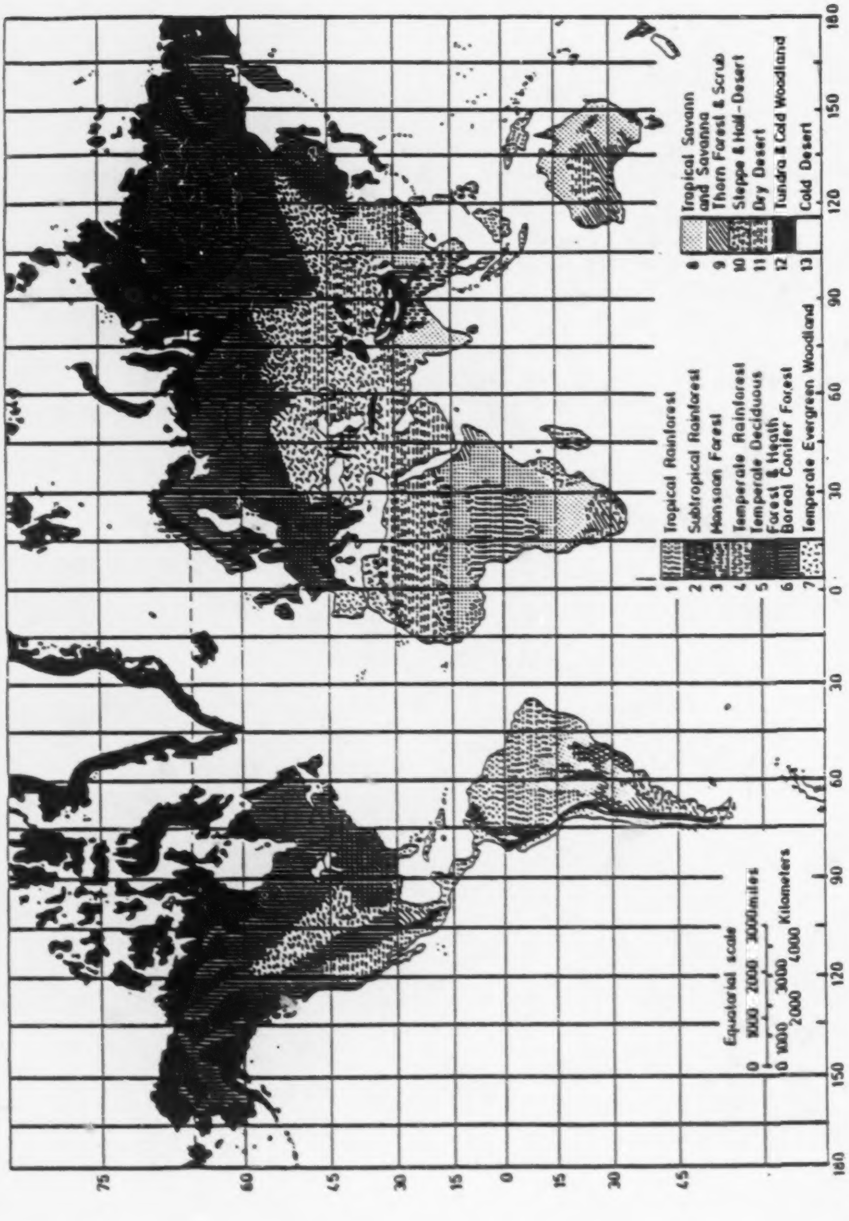
[a] Highly generalized representation of consequences of various physical stresses on biological systems resulting from nuclear war. Includes both acute and chronic stresses and reflects large-scale effects rather than localized situations. Stresses are:

temp.	air temperature reductions	**UV-B**	increased uv-B from ozone depletion
light	incident sunlight reductions	**air pollutants**	toxic gases (e.g., O_3, SO_2, NO_x)
ppt.	precipitation reductions	**fire**	initiated by nuclear detonations or from increased frequency later.
rad.	fallout radiation		

Symbols in the chart reflect both the extent of the stress on the specified system and the vulnerability of that system to the specified stress. Open symbols represent consequences if stresses occurred in winter, closed symbols for stresses in summer. Symbols are:

summer	winter	
◆	◊	essentially no effect
●	○	low effect
●●	○○	medium effect
●●●	○○○	large effect
●●●●	○○○○	extremely large effect



1 Tropical Rainforest
2 Subtropical Rainforest
3 Monsoon Forest
4 Temperate Rainforest
5 Temperate Deciduous Forest & Heath
6 Boreal Conifer Forest
7 Temperate Evergreen Woodland
8 Tropical Savann and Savanna
9 Thorn Forest & Scrub
10 Steppe & Half-Desert
11 Dry Desert
12 Tundra & Cold Woodland
13 Cold Desert
Equatorial scale
0 1000 2000 3000 miles
0 1000 2000 3000 4000 Kilometers
75
60
45
30
15
0
15
30
45
180
150
120
90
60
30
0
30
60
90
120
150
180

Figure 1

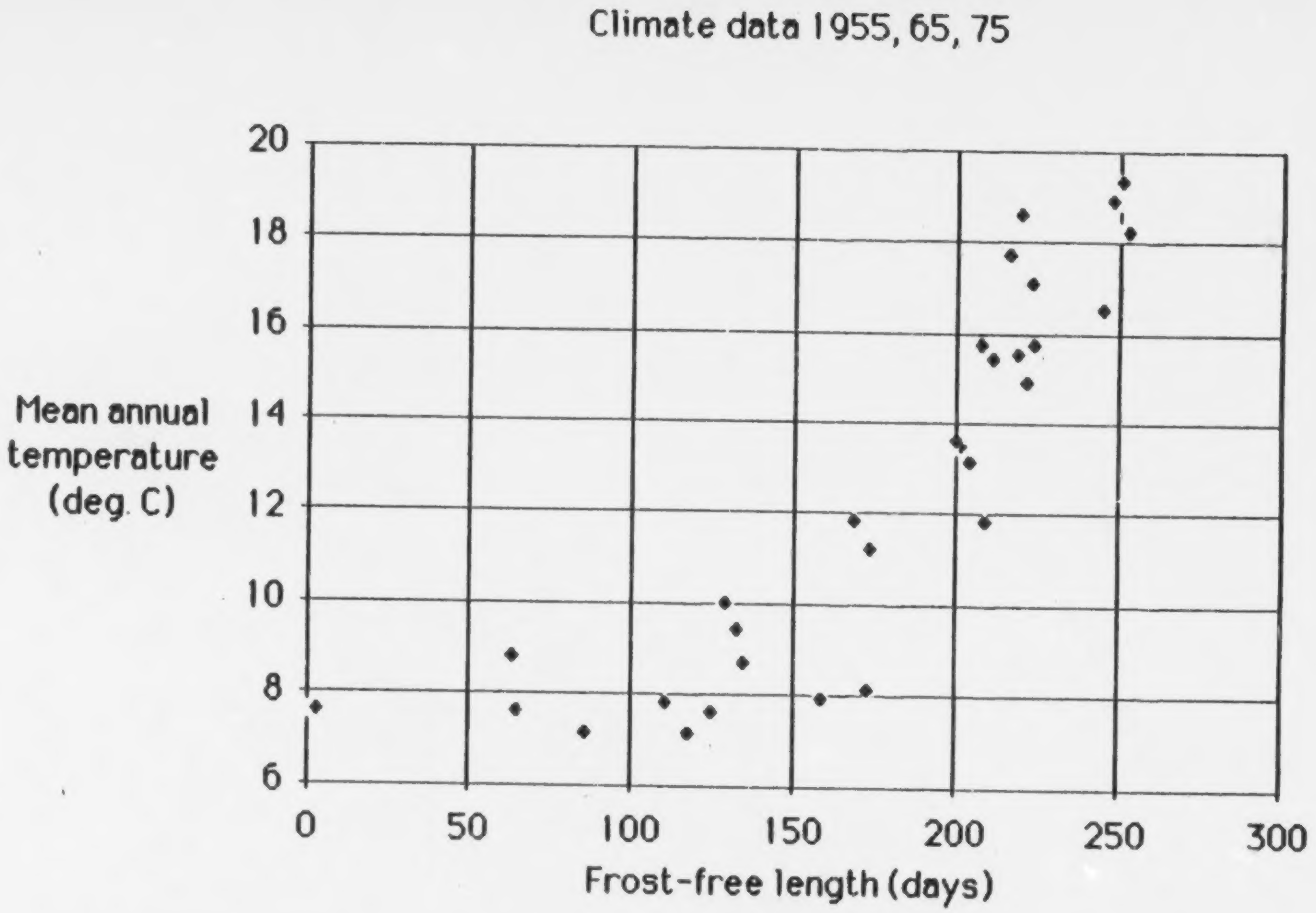

Climate data 1955, 65, 75
Mean annual temperature (deg. C)
20
18
16
14
12
10
8
6
0
50
100
150
200
250
300
Frost-free length (days)

Figure 2

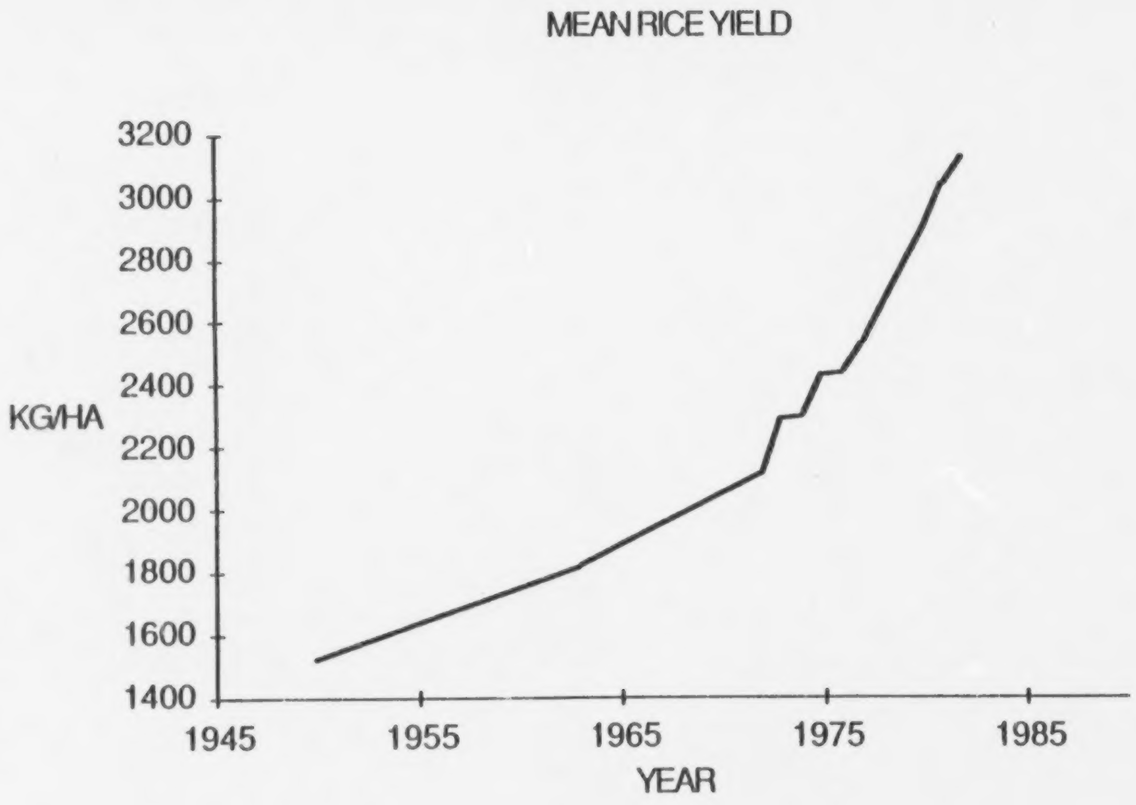

MEAN RICE YIELD
KG/HA
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1945
1955
1965
1975
1985
YEAR

Figure 3

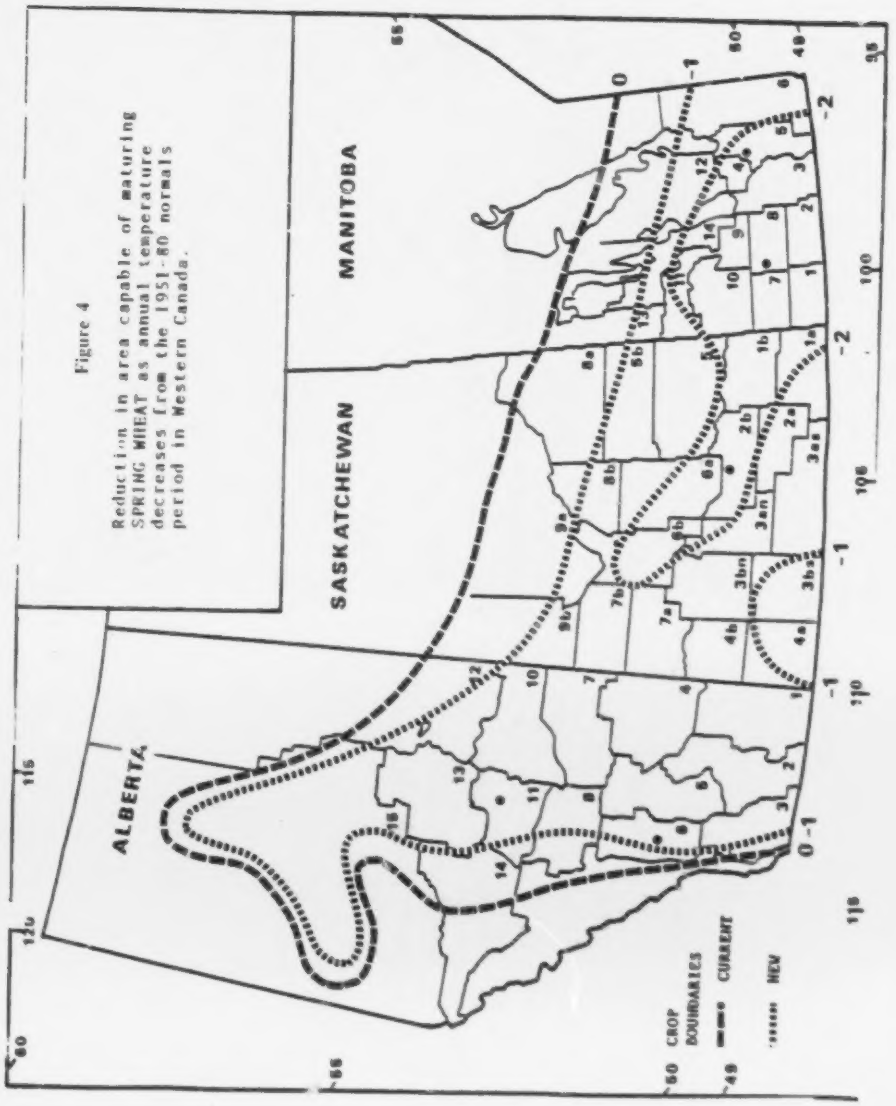


Figure 4

Reduction in area capable of maturing SPRING WHEAT as annual temperature decreases from the 1951-80 normals period in Western Canada.

ALBERTA
SASKATCHEWAN
MANITOBA
CROP BOUNDARIES
CURRENT
NEW
60
55
50
49
120
115
110
105
100
95
0
-1
-2
0 -1

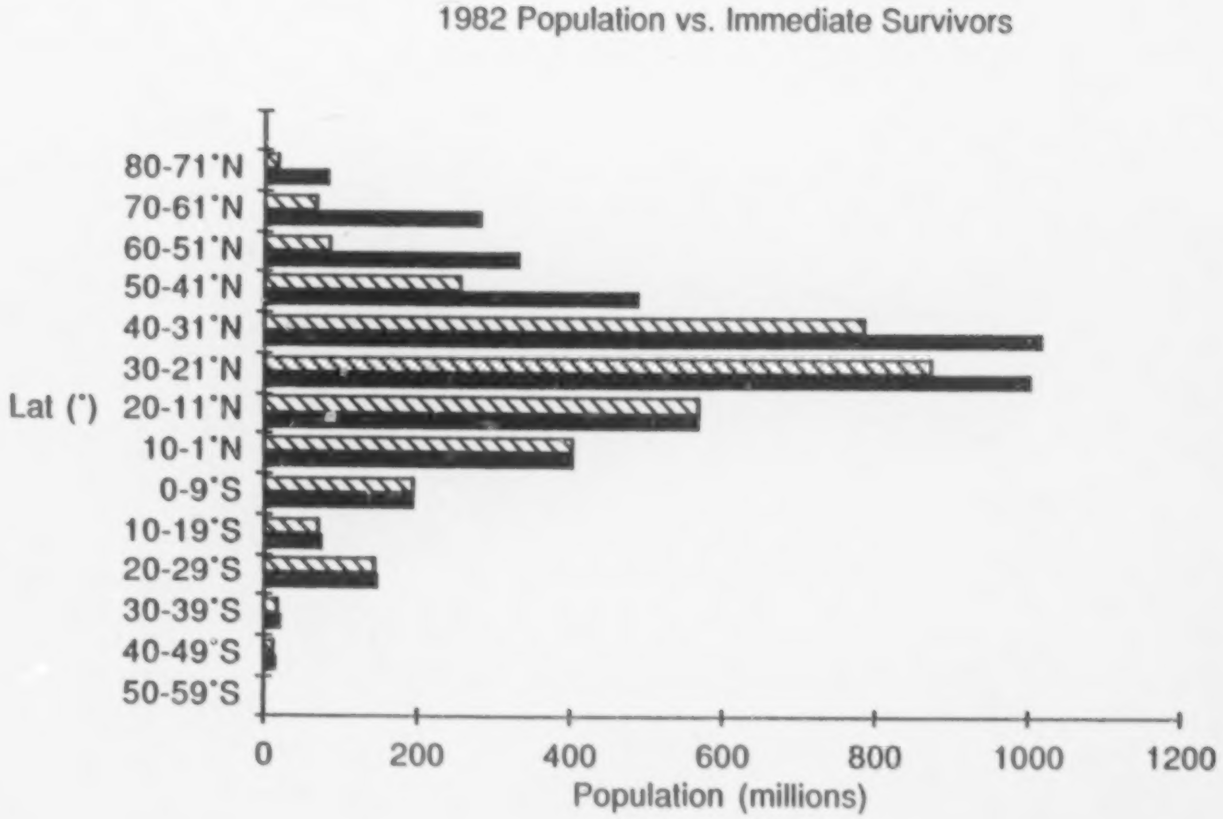

1982 Population vs. Immediate Survivors
Lat (°)
80-71°N
70-61°N
60-51°N
50-41°N
40-31°N
30-21°N
20-11°N
10-1°N
0-9°S
10-19°S
20-29°S
30-39°S
40-49°S
50-59°S
0
200
400
600
800
1000
1200
Population (millions)

Figure 5a

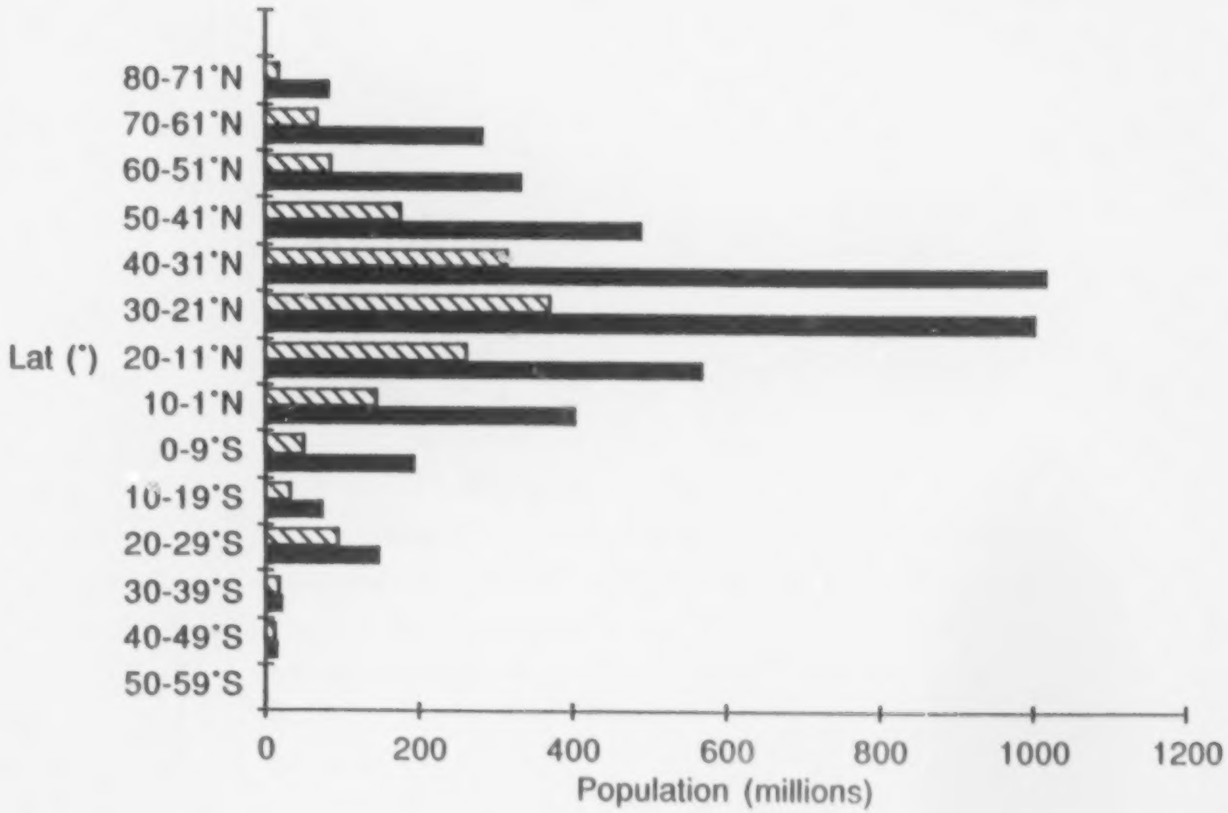

80-71°N
70-61°N
60-51°N
50-41°N
40-31°N
30-21°N
Lat (°)
20-11°N
10-1°N
0-9°S
10-19°S
20-29°S
30-39°S
40-49°S
50-59°S
0
200
400
600
800
1000
1200
Population (millions)

Figure 5b

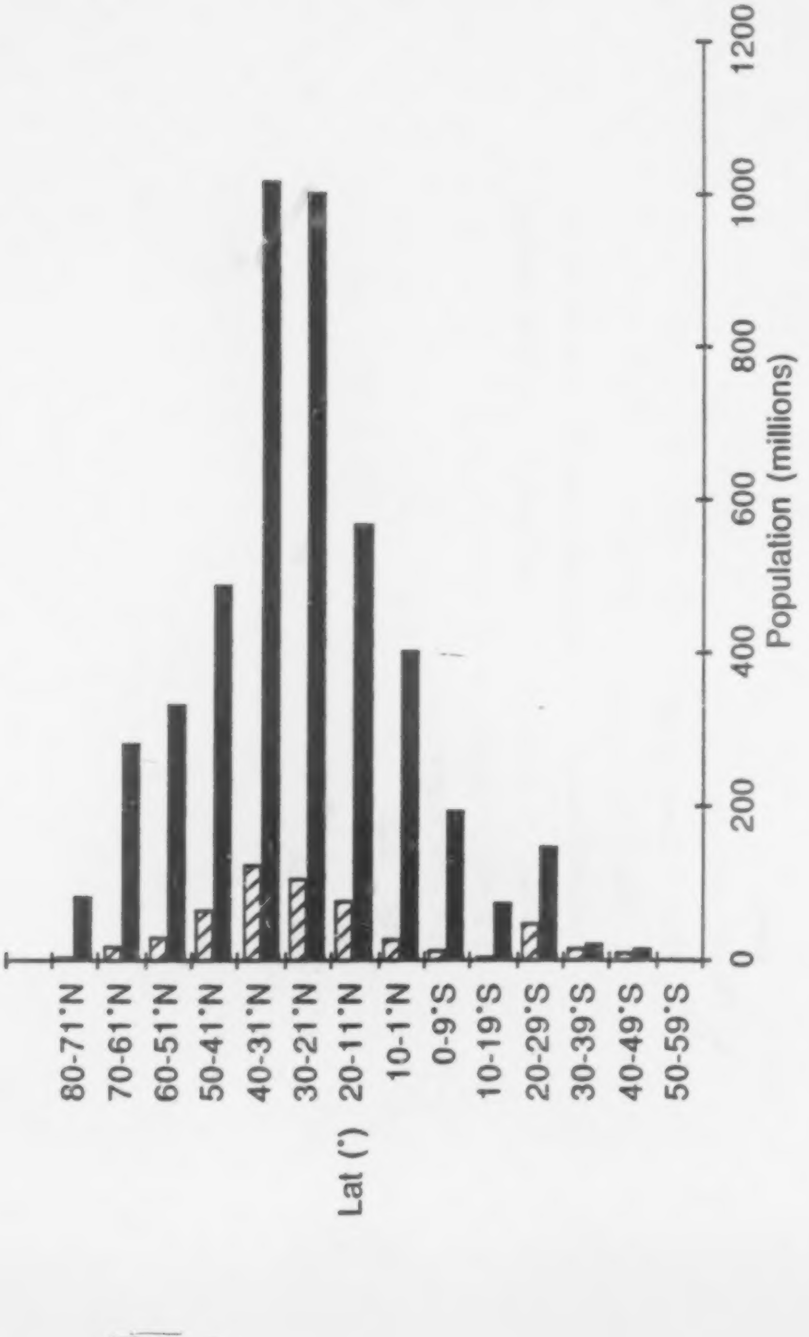
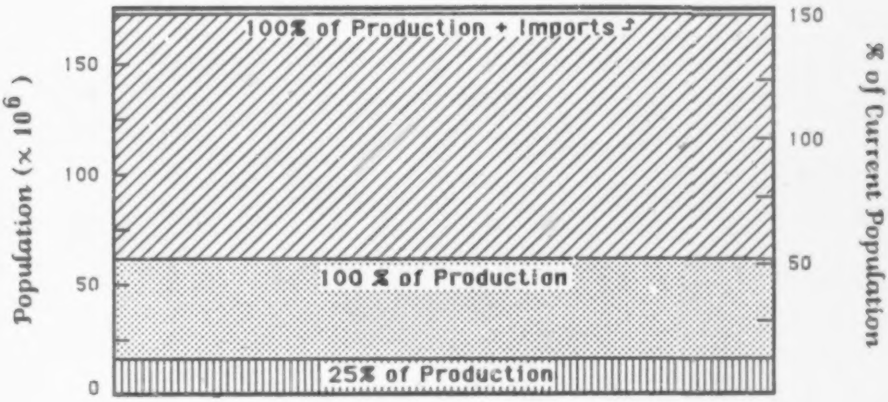

Lat (°)
80-71°N
70-61°N
60-51°N
50-41°N
40-31°N
30-21°N
20-11°N
10-1°N
0-9°S
10-19°S
20-29°S
30-39°S
40-49°S
50-59°S
Population (millions)
0
200
400
600
800
1000
1200

Figure 5c

Agricultural Effects of Nuclear War:
Chronic Phase



Japan

Figure 6

ENVIRONMENTAL CONSEQUENCES
OF
NUCLEAR WAR

SCOPE 28

VOLUME 1. PHYSICAL AND ATMOSPHERIC EFFECTS

EXECUTIVE SUMMARY

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R. P. Turco

This volume presents the results of an assessment of the climatic climatic effects and atmospheric effects of a large nuclear war. The chapters in the volume follow a logical sequence of development, starting with discussions of nuclear weapons effects and possible characteristics of a nuclear war. The report continues with a treatment of the consequent fires, smoke emissions, and dust injections and their effects on the physical and chemical processes of the atmosphere. This is followed by a chapter dealing with long-term radiological doses. The concluding chapter contains recommendations for future research and study.

In assessments of this type, a variety of procedural options are available, including, for example, "worst case" analyses, risk analyses, and "most probable" analyses. All of these approaches have relevance for the subject addressed here due to the large uncertainties which surround many aspects of the problem. Some of these uncertainties are inherent in studies of nuclear war and some are simply the result of limited information about natural physical processes. In general, in making assumptions about scenarios, models, and magnitudes of injections, and in estimating their atmospheric effects, an attempt has been made to avoid "minimum" and "worst case" analyses in favor of a "middle ground" that encompasses, with reasonable probability, the atmospheric and climatic consequences of a major nuclear exchange.

The principal results of this assessment, arranged roughly in the same order as the more detailed discussions contained in the body of this volume, are summarized below. The Executive Summary of Volume II (Harwell and Hutchinson, 1985), which describes the ecological and agricultural consequences of a nuclear war, is included Appendix 1 at the end of this volume. A Glossary is included as Appendix 2 and a list of participants in the study is included as Appendix 3.

1. DIRECT EFFECTS OF NUCLEAR EXPLOSIONS

The two comparatively small detonations of nuclear weapons in Japan in 1945 and the subsequent atmospheric nuclear tests preceding the atmospheric test ban treaty of 1963 have provided some information on the direct effects of nuclear explosions. Typical modern weapons carried by today's missiles and aircraft have yields of hundreds of kilotons or more. If detonated, such explosions would have the following effects:

- In each explosion, thermal radiation thermal (heat) radiation and blast waves would result in death and devastation over an area of up to 500 km^2 per megaton of yield, an area typical of a major city. The extent of these direct effects depends on the yield of the explosion, height of burst, and state of the local environment. The destruction of Hiroshima and Nagasaki by atomic bombs near the end of World War II provides examples of the effects of relatively *small* nuclear explosions.
- Nuclear weapons are extremely efficient incendiary devices. The thermal radiation wildland fires emitted by the nuclear fireball, in combination with the accidental ignitions caused by the blast, would ignite fires in urban/industrial areas and wildlands of a size unprecedented in history. These fires would generate massive plumes of smoke and toxic chemicals. The newly recognized atmospheric effects of the smoke from a large number of such fires are the major focus of this report.
- For nuclear explosions that contact land surfaces (surface bursts), large amounts (of the order of 100,000 tonne per megaton of yield) of dust, soil, and debris are drawn up with the fireball. The larger dust particles, carrying about half of the bomb's radioactivity, fall back to the surface

mostly within the first day, thereby contaminating hundreds of square kilometers near and downwind of the explosion site. This local fallout can exceed the lethal dose level.

- All of the radioactivity from nuclear explosions well above the surface (airbursts) and about half of the radioactivity from surface bursts would be lofted on very small particles into the upper troposphere or stratosphere by the rising fireballs and contribute to longer term radioactive fallout on a global scale.
- Nuclear explosions high in the atmosphere, or in space, would generate an intense electromagnetic pulse capable of inducing strong electric currents that could damage electronic equipment and communications networks over continent-size regions.

2. STRATEGIES AND SCENARIOS FOR A NUCLEAR WAR

In the forty years since the first nuclear explosion, the five nuclear powers, but primarily the U.S. and the U.S.S.R., have accumulated very large arsenals of nuclear weapons. It is impossible to forecast in detail the evolution of potential military conflicts. Nevertheless, enough of the general principles of strategic planning have been discussed that plausible scenarios for the development and immediate consequences of a large-scale nuclear war can be derived for analysis.

- NATO and Warsaw Pact nuclear arsenals include about 24,000 strategic warheads strategic and theatre nuclear theatre warheads warheads totaling about 12,000 megatons. The arsenals now contain the equivalent explosive power of about one million "Hiroshima-size" bombs.
- A plausible scenario for a global nuclear war could involve on the order of 6000 Mt divided between more than 12,000 warheads. Because of its obvious importance, the potential environmental consequences of an exchange of roughly this size are examined. The smoke-induced atmospheric consequences discussed in this volume are, however, more dependent on the number of nuclear explosions occurring over cities and industrial centers than on any of the other assumptions of the particular exchange.
- Many targets of nuclear warheads, such as missile silos and some military bases, are isolated geographically from population centers. Nevertheless, enough important military and strategic targets are located near or within cities so that collateral damage in urban and industrial centers from a counterforce nuclear strike could be extensive. As a result, even relatively limited nuclear attacks directed at military-related targets could cause large fires and smoke production.

- Current counter value strategic deterrence policies imply that, in an escalating nuclear conflict, many warheads might be used directly against urban and industrial centers. Such targeting would have far-reaching implications because of the potential for fires, smoke production, and climatic change.

3. THE EXTENT OF FIRES AND GENERATION OF SMOKE

During World War II, intense city fires covering areas as large as 10 to 30 square kilometers were ignited by massive incendiary bombing raids, as well as by the relatively small nuclear explosions over Hiroshima and Nagasaki. Because these fires were few in number and distributed over many months, the total atmospheric accumulation of smoke generated by these fires was small. Today, in a major wildland fires nuclear conflict, thousands of very intense fires, each covering up to a few hundred square kilometers, could be ignited simultaneously in urban areas, fossil fuel fires fossil fuel processing plants and storage depots, wildlands, and other locations. Because there have never been fires as large and as intense as may be expected, no appropriate smoke emission measurements have been made. Estimates of emissions from such fires rely upon extrapolation from data on much smaller fires. This procedure may introduce considerable error in quantifying smoke emissions, especially in making estimates for intense fire situations.

- About 70% of the populations of Europe, North America and the Soviet Union live in urban and suburban areas covering a few hundred thousand square kilometers and containing more than ten thousand million tonne of combustible wood and paper. If about 25–30% of this were to be ignited, in just a few hours or days, tens of millions to more than a hundred million tonne of smoke could be generated. About a quarter to a third of the emitted smoke from the flaming combustion of this material would be amorphous elemental carbon, which is black and efficiently absorbs sunlight.
- Fossil fuels (e.g., oil, gasoline, and kerosene) and fossil fuel-derived products (including plastics, rubber, asphalt, roofing materials, and organochemicals) are heavily concentrated in cities and industrial areas; flaming combustion of a small fraction (~25–30%) of the few thousand million tonne of such materials currently available could generate 50–150 million tonne of very sooty smoke containing a large fraction (50% or greater) of amorphous elemental carbon. About 25–30% of the combustible materials of the developed world are contained in less than one hundred of the largest industrialized urban areas.

- Fires ignited in forests and other wildlands could consume tens to hundreds of thousands of square kilometers of vegetation over days to weeks, depending on the state of the vegetation, and the extent of firespread. These fires could produce tens of millions of tonne of smoke in the summer half of the year, but considerably less in the winter half of the year. Because wildland fire smoke contains only about 10% amorphous elemental carbon, it would be of secondary importance compared to the smoke created by urban and industrial fires, although its effects would not be negligible.
- The several tens of millions of tonne of sub-micron dust particles that could be lofted to stratospheric altitudes by surface bursts could reside in the atmosphere for a year or more. The potential climatic effects of the dust emissions, although substantially less than those of the smoke, also must be considered.

4. THE EVOLUTION AND RADIATIVE EFFECTS OF THE SMOKE

The sooty smoke particles rising in the hot plumes of large fires would consist of a mixture of amorphous elemental carbon, condensed hydrocarbons, debris particles, and other substances. The amount of elemental carbon in particles with effective spherical diameters on the order of 0.1 μm to perhaps 1.0 μm would be of most importance in calculating the potential effect on solar radiation. Such particles can be spread globally by the winds and remain suspended for days to months.

- Large hot fires create converging surface surface winds, induced winds and rapidly rising fire plumes which, within minutes, can carry smoke particles, ash and other fire products, windblown debris, and water from combustion and the surrounding air to as high as 10–15 kilometers. The mass of particles deposited aloft would depend on the rate of smoke generation, the intensity of the fire, local weather conditions, and the effectiveness of scavenging processes in the convective column.
- As smoke-laden, heated air from over the fire rises, adiabatic expansion and entrainment would cause cooling and condensation of water vapor that could lead, in some cases, to the formation of a cumulonimbus cloud system. Condensation-induced latent heating of the rising air parcels would help to loft the smoke particles to higher altitudes than expected from the heat of combustion alone.
- Although much of the water vapor drawn up from the boundary layer would condense, precipitation might form for only a fraction of the fire plumes. In the rising columns of such fires, soot particles would tend to be collected inefficiently by the water in the cloud. Smoke particles however, are generally composed of a mixture of substances and might, at least partially, be incorporated in water droplets or ice particles by processes

not now well understood. Smoke particles that are captured could again be released to the atmosphere as the ice or water particles evaporate in the cloud anvils or in the environment surrounding the convective clouds. Altogether, an unknown fraction of the smoke entering the cloud would be captured in droplets and promptly removed from the atmosphere by precipitation.

- Not all fires would, however, induce strong convective activity. This depends on fuel loading characteristics and meteorological conditions. It is assumed in current studies that 30–50% of the smoke injected into the atmosphere from all fires would be removed by precipitation within the first day, and not be available to affect longer-term large-scale, meteorological processes. This assumption is a major uncertainty in all current assessments. For the fire and smoke assumptions made in this study, the net input of smoke to the atmosphere after early scavenging is estimated to range from 50 to 150 million tonne, containing about 30 million tonne of amorphous elemental carbon.
- Smoke particles generated by urban and urban fires fossil fuel fires would be strong absorbers of solar radiation, but would be likely to have comparatively limited effects on terrestrial longwave radiation, except perhaps under some special circumstances. If 30 million tonne of amorphous elemental carbon were produced by urban/industrial fires and spread over Northern Hemisphere mid-latitudes, the insolation at the ground would be reduced by at least 90%. The larger quantities of smoke that are possible in a major nuclear exchange could reduce light levels under dense patches to less than 1% of normal, and, after the smoke has spread widely, to just several percent of normal on a daily average.
- Because of the large numbers of particles in the rising smoke plumes and the very dense patches of smoke lasting several days thereafter, coagulation (adhering collisions) would lead to formation of fewer, but somewhat larger, particles. Coagulation of the particles could also occur as a result of coalescence and subsequent evaporation of rain droplets or ice particles. Because optical properties of aerosols are dependent on particle size and morphology, the aggregated aerosols may have different optical properties than the initial smoke particles, but the details, and even the sign, of such changes are poorly understood. The optical properties of fluffy soot aggregates that may be formed in dense oil plumes, however, seem to be relatively insensitive to their size. This is less the case for more consolidated particle agglomerates.
- Little consideration has yet been given to the possible role of meteorological processes on domains between fire plume fire plumes and continental scales. Mesoscale and synoptic-scale motions might significantly alter, mix, or remove the smoke particles during the first several days. Studies to examine quantitatively the microphysical evolution of smoke particles during

this period are needed. While changes in detailed understanding are expected, a significant fraction of the injected smoke particles is likely to remain in the atmosphere and affect the large-scale weather and climate.

5. SMOKE-INDUCED ATMOSPHERIC PERTURBATIONS

In a major nuclear war, continental scale smoke clouds could be generated within a few days over North America, Europe, and much of Asia. Careful analysis and a hierarchy of numerical models (ranging from one-dimensional models one-dimensional GCMs global-average to three-dimensional global-scale models) have been used to estimate the transport, transformation, and removal of the smoke particles and the effects of the smoke on temperature, precipitation, winds, and other important atmospheric properties. All of the simulations indicate a strong potential for large-scale weather disruptions as a result of the smoke injected by extensive post-nuclear fires. These models, however, still have important simplifications and uncertainties that may affect the fidelity and the details of their predictions. Nonetheless, these uncertainties probably do not affect the general character of the calculated atmospheric response.

- For large smoke injections reaching altitudes of several kilometers or more and occurring from spring through early fall in the Northern Hemisphere, average land surface temperatures beneath dense smoke patches could decrease by 20–40°C below normal in continental areas within a few days, depending on the duration of the dense smoke pall and the particular meteorological state of the atmosphere. Some of these patches could be carried long distances and create episodic cooling. During this initial period of smoke dispersion, temperature anomalies could be spatially and temporally quite variable while patchy smoke clouds strongly modulate the insolation reaching the surface.
- Smoke particles would be spread throughout much of the Northern Hemisphere within a few weeks, although the smoke layer would still be far from homogeneous. For spring to early fall injections, solar heating of the particles could rapidly warm the smoke layer and lead to a net upward motion of a substantial fraction of the smoke into the upper troposphere and stratosphere. The warming of these elevated layers could stabilize the atmosphere and suppress vertical movement of the air below these layers, thereby extending the lifetime of the particles from days to perhaps several months or more.
- Average summertime land surface temperatures in the Northern Hemisphere mid-latitudes could drop to levels typical of fall or early winter for periods of weeks or more with convective precipitation being essentially eliminated, except possibly at the southern edge of the smoke pall. Cold, near-surface air layers might lead initially to fog and drizzle, especially

in coastal regions, lowland areas, and river valleys. In continental interiors, periods of very cold, mid-winter-like temperatures are possible. In winter, light levels would be strongly reduced, but the initial temperature and precipitation perturbations would be much less pronounced and might be essentially indistinguishable in many areas from severe winters currently experienced from time to time. However, such conditions would occur simultaneously over a large fraction of the mid-latitude region of the Northern Hemisphere and freezing cold air outbreaks could penetrate southward into regions that rarely or never experience frost conditions.

- In Northern Hemisphere subtropical latitudes, temperatures in any season could drop well below typical cool season conditions for large smoke injections. Temperatures could be near or below freezing in regions where temperatures are not typically strongly moderated by warming influence from the oceans. The convectively driven monsoon circulation, which is of critical importance to subtropical ecosystems, agriculture, and is the main source of water in these regions, could be essentially eliminated. Smaller scale, coastal precipitation might, however, be initiated.
- Strong solar heating of smoke injected into the Northern Hemisphere between April and September would carry the smoke upwards and equatorward, strongly augmenting the normal high altitude flow to the Southern Hemisphere (where induced downward motions might tend to slightly suppress precipitation). Within one or two weeks, thin, extended smoke layers could appear in the low to mid-latitude regions of the Southern Hemisphere as a precursor to the development of a more uniform veil of smoke with a significant optical depth (although substantially smaller than in the Northern Hemisphere). The smoke could induce modest cooling of land areas not well buffered by air masses warmed over nearby ocean areas. Since mid-latitudes in the Southern Hemisphere would already be experiencing their cool season, temperature reductions would not likely be more than several degrees. In more severe, but less probable, smoke injection scenarios, climatic effects in the Southern Hemisphere could be enhanced significantly, particularly during the following austral spring austral spring and summer.
- Much less analysis has been made of the atmospheric perturbations following the several week, acute climatic phase subsequent to a nuclear war involving large smoke injections. Significant uncertainties remain concerning processes governing the longer-term removal of smoke particles by precipitation scavenging, chemical oxidation, and other physical and chemical factors. The ultimate fate of smoke particles in the perturbed atmospheric circulation is also uncertain, both for particles in the sunlit and stabilized upper troposphere and stratosphere and in the winter polar regions, where cooling could result in subsidence that could move particles downward from

the stratosphere to altitudes where they could later be scavenged by precipitation.

- Present estimates suggest that smoke lofted (either directly by fire plumes or under the influence of solar heating) to levels which are, or become, stabilized, could remain in the atmosphere for a year or more and induce long-term (months to years) global-scale cooling of several degrees, especially after the oceans have cooled significantly. For such conditions, precipitation could also be reduced significantly. Reduction of the intensity of the summer monsoon over Asia and Africa could be a particular concern. Decreased ocean temperatures, climatic feedback mechanisms (e.g., ice-albedo feedback), and concurrent ecological changes could also prolong the period of meteorological disturbances.

6. ATMOSPHERIC CHEMISTRY IN A POST-NUCLEAR-WAR ENVIRONMENT

Nuclear explosions and the resultant fires could generate large quantities of chemical compounds that might themselves be toxic. In addition, the chemicals could alter the atmospheric composition and radiative fluxes in ways that could affect human health, the biosphere, and the climate.

- Nitrogen oxides (NO_x) created in nuclear fireballs would be lofted primarily into the stratosphere for explosions of greater than several hundred kilotons. Depending on the total number of high yield weapons exploded, the NO_x would catalyze chemical reactions that, within a few months time, could reduce Northern Hemisphere stratospheric ozone concentrations by 10 to 30% in an atmosphere free of aerosols. Recovery would take several years. However, if the atmosphere were highly perturbed due to smoke heating and by injection of gaseous products from fires, the long-term ozone changes could be enhanced substantially in ways that cannot yet be predicted.
- Stratospheric ozone reductions of tens of percent could increase surface intensities of biologically-active ultraviolet (UV) radiation by percentages of up to a few times as much. The presence of smoke would initially prevent UV-radiation from reaching the surface by absorbing it. The smoke, however, might also prolong and further augment the long-term ozone reduction as a result of smoke-induced lofting of soot and reactive chemicals, consequent heating of the stratosphere, and the occurrence of additional chemical reactions.
- Large amounts of carbon monoxide, hydrocarbons, nitrogen and sulfur oxides, hydrochloric acid, pyrotoxins, heavy metals, asbestos, and other materials would be injected into the lower atmosphere near the surface by flaming and smoldering combustion of several thousand million tonne of cellulosic and fossil fuel products and wind-blown debris. Before deposition

or removal, these substances, some of which are toxic, could be directly and/or indirectly harmful to many forms of life. In addition, numerous toxic toxic compounds chemical compounds could be released directly into the environment by blast and spillage, contaminating both soil and water. This complex and potentially very serious subject has so far received only cursory consideration.

- If the hydrocarbons and nitrogen oxides were injected into an otherwise unperturbed troposphere, they could enhance average background ozone concentrations several-fold. Such ozone increases would not significantly offset the stratospheric ozone decrease, which also would be longer lasting. It is highly questionable, however, whether such large ozone increases could indeed occur in the presence of smoke because ozone generation in the troposphere requires sunlight as well as oxides of nitrogen. It is possible that, in the smoke perturbed atmosphere, the fire-generated oxides of nitrogen could be removed before photochemical ozone production could take place.
- Precipitation scavenging of nitrogen, sulfur, and chlorine compounds dispersed by the fire plumes throughout the troposphere could increase rainfall acidity by about an order of magnitude over large regions for up to several months. This increased acidity might be neutralized to some degree by alkaline dust or other basic (as opposed to acidic) compounds.
- Rapid smoke-induced cooling of the surface under dense smoke clouds could induce the formation of shallow, stable cold layers that might trap chemical emissions from prolonged smoldering fires near the ground. In such layers, concentrations of CO, $HC\ell$, pyrotoxins, and acid fogs could reach dangerous levels. The potential for local and regional effects in areas such as populated lowland areas and river valleys merits close attention.

7. RADIOLOGICAL DOSE

Near the site of an explosion, the health effects of prompt ionizing radiation from strategic nuclear warheads would be overshadowed by the effects of the blast and thermal radiation. However, because nuclear explosions create highly radioactive fission products and the emitted neutrons may also induce radioactivity in initially inert material near the detonation, radiological doses would be delivered to survivors both just downwind (local fallout) and out to hemispheric and global scales (global fallout).

- Local fallout of relatively large radioactive particles lofted by the number of surface explosions in the scenario postulated in this study could lead to lethal external gamma-ray doses (assuming no protective action is taken) during the first few days over about 7 percent of the land areas of the NATO and Warsaw Pact countries. Areas downwind of missile silos and other hardened targets would suffer especially high exposures. Survivors outside of lethal fallout zones could still receive debilitating radiation doses (exposure at half the lethal level can induce severe radiation sickness). In combination with other injuries or stresses, such doses could increase mortality. If large populations could be mobilized to move from highly radioactive zones or take substantial protective measures, the human impact of fallout could be greatly reduced.

- The uncertainty in these calculations of local fallout is large. Doses and areas for single nuclear explosions could vary by factors of 2–4 depending on meteorological conditions and assumptions in the models. A detailed treatment of overlapping fallout plumes from multiple explosions could increase the areas considerably (by a factor of 3 in one sample case). Results are also sensitive to variations in the detonation scenario.
- Global fallout following the gradual deposition of the relatively small radioactive particles created by strategic air and surface bursts could lead to average Northern Hemisphere lifetime external gamma ray doses on the order of 10 to 20 rads. The peak values would lie in the northern mid-latitudes where the average doses for the scenarios considered would be about 20 to 60 rads. Such doses, in the absence of other stresses, would be expected to have relatively minor carcinogenic and mutagenic effects (i.e., increase incidence at most a few percent above current levels). Smoke-induced perturbations that tend to stabilize the atmosphere and slow deposition of radioactive particles might reduce these estimated average doses by perhaps 15%.
- Intermediate time scale and long term global fallout would be deposited unevenly, largely because of meteorological effects, leading to "hotspots" of several hundred thousand square kilometers in which average doses could be as high as 100 rads, and, consequently, large areas where doses would be lower than the average value.
- In the Southern Hemisphere and tropical latitudes, global fallout would produce much smaller, relatively insignificant, radiological doses about one-twentieth those in the Northern Hemisphere, even if cross-equatorial transport were accelerated by the smoke clouds. Additional local fallout would be important only within a few hundred kilometers downwind of any surface burst in the Southern Hemisphere.
- Additional considerations not factored into the above estimates are possible from several sources. Doses from ingestion or inhalation of radioactive particles could be important, especially over the longer term. Beta radiation could have a significant effect on the biota coming into contact with the local fallout. Fission fractions of smaller modern weapons could be twice the assumed value of 0.5; adding these to the scenario mix could cause a 20% increase in areas of lethal fallout. General tactical and theater nuclear weapons, ignored in these calculations, could also cause a 20%

increase in lethal local fallout areas in certain geographical regions, particularly in Europe. The injection into the atmosphere of radionuclides created and stored by the civilian nuclear power industry and military reactors, a possibility considered remote by some, could increase estimates of long-term local and global radiological doses to several times those estimated for weapons alone.

8. TASKS FOR THE FUTURE

Extensive research and careful assessment over the past few years have indicated that nuclear war has the potential to modify the physical environment in ways that would dramatically impair biological processes. The perturbations could impact agriculture, the proper functioning of natural ecosystems, the purity of essential air and water resources, and other important elements of the global biosphere. Because current scientific conclusions concerning the response of the atmosphere to the effects of nuclear war include uncertainties, research can and should be undertaken to reduce those uncertainties that are accessible to investigation.

- Laboratory and field experiments are needed to improve estimates of the amount and physical characteristics of the smoke particles that would be produced by large fires, particularly by the combustion of fossil fuels and fossil fuel-derived products present in urban and industrial regions. Experimental conditions should be designed to emulate as much as possible the effects of large-scale fires.
- Laboratory, field, and theoretical studies are needed to determine the potential scavenging rates of smoke particles in the convective plumes of large fires and the scavenging processes that operate on intermediate and global scales as the particles disperse.
- Further theoretical calculations of the seasonal response of the atmosphere to smoke emissions from large fires are needed, particularly of the extent of the perturbation to be expected at early times, when the smoke is freshly injected and patchy. Simulations must be made for later times from months to a year or more, when the atmosphere has been highly perturbed and a substantial fraction of the smoke may have been lofted to high altitudes. Closer attention should be paid to the possible effects in low latitudes and in the Southern Hemisphere, where the climatic effects are likely to be much more important than the direct effects of the nuclear detonations, which are expected to be confined largely to the Northern Hemisphere.
- Laboratory and theoretical studies are needed of the potential chemical alterations of the atmosphere on global and local scales, and of the extent that smoke particles could affect and might be removed by chemical reactions high in the atmosphere.

- Radiological calculations should be undertaken using models that more realistically treat the overlap of fallout plumes, complex meteorological conditions, and that consider both external and internal doses. Patterns of land use and likely targeting strategy should be used in estimating the potential significance of various scenarios. The question of the possible release of radioactivity from nuclear fuel cycle facilities in a nuclear war should be explored more thoroughly.

AUTHORS' NOTE

The term "nuclear winter" has been applied in some previous analyses of the environmental consequences of a nuclear exchange to describe the multitude of possible effects. In its original usage, this term envisaged the combination of darkened skies, subfreezing temperatures, and extensive toxic and radioactive pollution that, to a more or less severe degree, might follow a nuclear war. The phrase has since, however, come to be associated primarily with the most severe possibilities. Although it is a convenient metaphor for use in describing the generic consequences, we have chosen to avoid use of the term "nuclear winter" in this study because it does not, in a strict scientific sense, properly portray the range, complexity, and dependencies of the potential global scale environmental consequences of a nuclear war. By this choice, we are not suggesting that the environmental effects of a major nuclear exchange would be inconsequential; to the contrary, we find that they would be substantial and significant.

ENVIRONMENTAL CONSEQUENCES OF NUCLEAR WAR
VOLUME II: ECOLOGICAL AND AGRICULTURAL EFFECTS

by Mark A. Harwell and Thomas C. Hutchinson

EXECUTIVE SUMMARY

The potential consequences to the global environment of a nuclear war have been the focus of several studies in the four decades since the first detonations of nuclear weapons in Japan. During this time, the potential consequences that would ensue from a modern nuclear war have increased dramatically, and the combination of much larger yields and much greater numbers of nuclear warheads could now result in a large-scale nuclear war having little in common with the relatively limited experiences of Hiroshima and Nagasaki. Simultaneously, the projections of the magnitude of impacts from a nuclear war have also increased steadily; however, the perception of the consequences of a large-scale nuclear war consistently have lagged behind the reality. New global-scale phenomena continue to be identified, even up to the present, and there remains a concern that decision-makers are operating with obsolete analyses and basing their policies on a foundation of misunderstanding of the total consequences of nuclear war.

The SCOPE-ENUWAR project had as one of its objectives the development of a comprehensive understanding of the nature of a post-nuclear war world, based on the full range of available information and models. Volume I of the ENUWAR report presented the bases for estimating potential effects on the physical environment, including possible climatic disturbances as well as fallout, UV-B, air pollutants, and other effects. The present volume takes up where the first left off, by specifically considering the potential consequences of such physical and chemical stresses on biological systems and on the ultimate endpoint of concern, i.e., effects on the global human population.

The approach taken in the biological analyses was to synthesize current understanding of the responses of ecological and agricultural systems to perturbations, relying on the expertise of over 200 scientists from over 30 countries around the Earth. Much of the synthesis took place in the context of a series of workshops that addressed specific issues; other work included conducting simulation modelling and performing detailed calculations of potential effects on the human populations of representative countries. We do not present the evaluation of a single nuclear war scenario as estimated by a single methodology; rather, a suite of methodologies were drawn upon collectively to develop an image of the aftermath of a large-scale nuclear war. The range of possible nuclear war scenarios is great; the estimates from the physical scientists of potential climatic consequences are not yet certain and continue to evolve with time. Those estimates are complex in their spatial and temporal distribution over the Earth, and the global landscape is covered by extremely complex ecological, agricultural, and human systems that react to perturbations in complex manners. For these reasons, the present volume investigates the vulnerability of these systems to the types of perturbations possible after a nuclear war, offering readers the opportunity to form their own specific projections of biological and human consequences by providing calculations of vulnerabilities to benchmark assumptions.

Nevertheless, many conclusions are evident from considering these vulnerabilities to nuclear war perturbations. These include:

- Natural ecosystems are vulnerable to extreme climatic disturbances, with differential vulnerability depending on the ecosystem type, location, and season of effects. Temperature effects would be dominant for terrestrial ecosystems in the Northern Hemisphere and in the tropics and sub-tropics; light reductions would be most important for oceanic ecosystems; precipitation effects would be more important to grasslands and many Southern Hemisphere ecosystems.

- The potential for synergistic responses and propagation of effects through ecosystems implies much greater impacts than can be understood by addressing perturbations in isolation. For example, increased exposure to UV-B and to mixtures of air pollutants and radiation, while not crucially harmful for any one stress, might collectively be very detrimental or lethal to sensitive systems because of synergistic interactions.

- Fires as a direct consequence of a major nuclear exchange could consume large areas of natural ecosystems, but fire-vulnerable ecosystems are generally adapted to survive or regenerate via a post-fire succession. Other direct effects of nuclear detonations on ecological systems would be limited in extent or effect.

- The recovery of natural ecosystems from the climatic stresses postulated for an acute phase following following a major nuclear war would depend on normal adaptations to disturbance, such as through presence of spores, seed banks, seedling banks, vegetative growth, and coppicing. For some systems, the initial damage could be very great and recovery very slow, with full recovery to the pre-disturbed state being unlikely. Human-ecosystem interactions could act to retard ecological recovery.

- Because of limitations in the amounts of utilizable energy, natural ecosystems cannot replace agricultural systems in supporting the majority of humans on Earth, even if those natural ecosystems were not to suffer any impacts from nuclear war.

- Consequently, human populations are highly vulnerable to disruptions in agricultural systems.

- Agricultural systems are very sensitive to climatic and societal disturbances occurring on regional to global scales, with reductions in or even total loss of crop yields possible in response to many of the potential stresses. These conclusions consistently follow from a suite of approaches to evaluating vulnerabilities, including historical precedents, statistical analyses, physiological and mechanistic relationships, simulation modelling, and reliance on expert judgment.

- The vulnerabilities of agricultural productivity to climatic perturbations are a function of a number of different factors, any one of which could be limiting. These factors include: insufficient integrated thermal time for crops over the growing season; shortening of the growing season by reduction in a frost-free period in response to average temperature reductions; increasing of the time required for crop maturation in response to reduced temperatures; the combination of the latter two factors to result in insufficient time for crops to mature prior to onset of killing cold temperatures; insufficient integrated time of sunlight over the growing season for crop maturation; insufficient precipitation for crop yields to remain at high levels; and the occurrence of brief episodic events of chilling or freezing temperatures at critical times during the growing season.

- Potential disruptions in agricultural productivity and/or in exchange of food across national boundaries in the aftermath of a large-scale nuclear war are factors to which the human population is highly vulnerable. Vulnerability is manifested in the quantities and duration of food stores existing at any point in time, such that loss of the continued agricultural productivity or imports that maintain food levels would lead to depletion of food stores for much of the world's human population in a time period before it is likely that agricultural productivity could be resumed.

- Under such a situation, the majority of the world's population is at risk of starvation in the aftermath of a nuclear war. Risk is therefore exported from combatant countries to non-combatant countries, especially those dependent on others for food and energy subsidies and those whose food stores are small relative to the population.

- The high sensitivity of agricultural systems to even relatively small alterations in climatic conditions indicates that many of the unresolved issues among the physical scientists are less important, since even their lower estimates of many effects could be devastating to agricultural production and thereby to human populations on regional or wider scales.

- Longer-term climatic disturbances, if they were to occur, would be at least as important to human survival as the acute, early extremes of temperature and light reductions, suggesting that much greater attention should be given to those issues. Similarly, much greater attention is needed to resolve uncertainties in precipitation reduction estimates, since many of the agricultural systems are water-limited, and reduced precipitation can significantly reduce total production.

- Factors related to the possibility and rates of redevelopment of an agricultural base for the human population would have much influence on the long-term consequences to the human population. Interactions with societal factors would be very important.

- Global fallout is not likely to result in major ecological, agricultural, or human effects, as compared to effects of other global disturbances. Local fallout, on the other hand, could be highly consequential to natural and agricultural systems and to humans; however, the extent of coverage of lethal levels of local fallout and the levels of internal doses to humans from such fallout are inadequately characterized.

- Human populations are highly vulnerable to possible societal disruptions within combatant and non-combatant countries after a large-scale nuclear war, such as in the consequent problems of distribution of food and other limited resources among the immediate survivors. This is an area requiring a level of serious scientific investigation that has not yet been brought to bear on these issues.

As a part of the SCOPE-ENUWAR project, a workshop was held in Hiroshima, Japan, in order for the scientists to gain a fuller appreciation of the human consequences of nuclear detonations. The considerations listed above indicate that as devastating as the Japanese atomic bombings were, as consequential to their victims even to the present day, and as important to the development of the 20th Century, they cannot provide a sense of what the global aftermath of a modern nuclear war could be like. Hiroshima today is a thriving, dynamic city reborn from complete devastation by interactions and support from the outside world; after a large-scale nuclear war, there would be essentially no outside world, and qualitatively new global-scale effects would occur that could devastate not just an urban population but the entirety of humanity. Although issues remain to be resolved, the information in this volume demonstrates some of the great vulnerabilities of agricultural, ecological, and societal support systems to the potential direct and indirect consequences of nuclear war. This demonstration of global frailties mandates the formulation of new global perspectives on avoiding the aftermath of nuclear war.

Chairman GOLDWATER. Thank you very much, Dr. Harwell.

Both Senator Nunn and I are going to have to be absent for a few minutes because of commitments on the floor. Senator Cohen will take over at that time.

Mr. Sloss has just arrived. We welcome you.

Mr. Sloss participated in the formulation of U.S. targeting policy and he will address the nuclear winter hypothesis from the perspective of targeting policy implications.

STATEMENT OF LEON SLOSS, PRESIDENT, LEON SLOSS ASSOCIATES, INC.

Mr. SLOSS. Senator Goldwater, gentlemen, I appreciate the opportunity to appear before this committee again on an issue that is of great importance to our national security.

I am not a technical expert, although I think I know enough from carefully studying the technical reports on the phenomena of nuclear winter. I will focus my remarks instead on policy issues with particular emphasis on nuclear strategy, targeting strategies and weapons systems.

I want to say a word about the importance of the issue of nuclear winter because I think it has both been exaggerated and underestimated in importance. It seems to me it is an extremely important issue, one that we do have to take seriously, at least the Government has to take it seriously.

I do feel, however, that some of the studies have exaggerated the phenomena because they have used scenarios that in my judgment are unrealistic.

The first thing I want to do is cover the scenarios. It is certainly possible to imagine nuclear wars in which there are large mass attacks on cities. It seems to me in these scenarios the nuclear winter phenomena are likely to be inconsequential in relation to the direct effects; that is, blast and fallout.

Therefore, I conclude that we ought to concentrate on scenarios in which the attack focuses on military targets, some of which will be cities, and not so much on the very large attacks on cities where, as I said, I think the direct effects will overwhelm the nuclear winter phenomena.

I believe we ought to concentrate our analysis on those attacks that could result in what I refer to as mild nuclear winters. There will still be very substantial effects from such attacks.

In postulating nuclear winter scenarios, we invariably must make an assumption about national strategy and the role of nuclear weapons in that strategy. There are different views on this.

Some people will argue that a limited nuclear war, in which cities are avoided or which minimizes attacks on cities, is unrealistic. Once nuclear weapons are used, they contend escalation to large-scale nuclear war would be automatic.

I don't agree with that view, but if indeed that were the case, then, as I suggested earlier we really ought to stop worrying about the nuclear winter effects, the direct effects will overwhelm them.

I do believe limited nuclear war is a possibility because all parties involved will have very strong interest in keeping it limited.

They may find it impossible to do so. I will address that question in a minute.

The United States has certainly made plans to limit use of nuclear weapons and to control escalation and we have reason to believe that the Soviet Union, while having different views of this and expressing skepticism in public, has the capability and plans which will permit them to conduct limited nuclear war.

Some observers also argue that planning limited nuclear war is dangerous because it will lead to acceptance of the possibility of nuclear war.

However, we can't avoid the fact that that possibility exists. It seems to me far worse to have no plans to control escalation or limit a nuclear war should that awful event occur. More important, every President and Secretary of Defense who has had to live with the responsibility for nuclear weapons seems to have arrived at the same conclusion.

It seems to me that if we are going to look, then, at the more limited cases, we ought to ask whether our plans and our weapons systems have adequately taken into account the nuclear winter phenomena.

I suggest in my written statement that there are some things that we can do and in fact that we have been doing in the design and development of our weapons systems that do indeed help reduce collateral damage, including large-scale climatic effects.

The overall yield of our strategic nuclear inventory has declined substantially over the past decade or more and I suggest that there are some other things that we can do by way of weapons design that could deal with nuclear winter phenomena even more.

One of these I call attention to is the so-called penetrating weapons, which will have shock effects without creating environmental effects. An example that suggests to me at least one area we ought to be working on if we are concerned about nuclear winter is the design of weapons.

I also suggest that we need, as we understand the phenomena better, we definitely have a lot to learn about the phenomena, that it is incumbent on the administration to reexamine the plans that they do have to assure that we are not unwittingly, and particularly with regard to the limited options that we have in our plans, we are not unwittingly creating global climatic effects as a result of those plans.

It might be premature, slightly premature, to do that at the present time based on the knowledge that we have, but I think that is an important thing to keep in mind and it is consistent with my view that this is not an inconsequential problem but needs to be taken seriously.

I sum up, then, and I am trying to skip over this quickly so that you will have a chance to comment, I sum up by saying that I believe that the phenomena associated with nuclear winter constitutes potential collateral effects that should be examined seriously.

More attention should be given to the worldwide climatic effects of more limited attacks and mild nuclear winter, and I believe there are things that we can do, if this appears necessary, to minimize nuclear winter effects, both through the design of weapons systems and the adjustment of war plans.

I will be happy to take your questions.

[The prepared statement of Mr. Sloss follows:]

PREPARED TESTIMONY OF LEON SLOSS

POLICY IMPLICATIONS OF NUCLEAR WINTER

I appreciate the opportunity to appear once again before this committee on a matter of importance to our national security. I am not here as an expert on the technical aspects of nuclear winter, although I have examined the major studies that have been undertaken by technical experts and I have a general understanding of the scientific phenomena insofar as we know them. Instead, I will focus my remarks on policy issues, with particular emphasis on nuclear strategy, targeting policy and weapons development.

First, I would like to say a few words about the importance of the nuclear winter issue because I think it has been both exaggerated and understated in public discussion. There is a great deal we do not yet know about the phenomenology associated with very large fires and firestorms and the resultant effects on the global environment. Yet, I believe that we know enough to take the issue of nuclear winter seriously. At the same time, I am concerned that some of the most widely publicized studies and statements on the subject have tended to exaggerate the problem by basing their analyses on unrepresentative scenarios of nuclear war.

Let me begin then by discussing scenarios. It is certainly possible to imagine nuclear wars in which there are large or massive attacks on cities, but in these scenarios the nuclear winter phenomena is likely to be inconsequential in relation to the direct effects (e.g., blast) and fallout. In my view, the scenarios on which we ought to concentrate our attention are those in which the attack focuses on military targets (some of which may indeed be in cities). These are cases where there could still be substantial worldwide climatic effects which would extend well beyond and possibly magnify the direct effects. For example, attacks on military targets in wooded areas could create large fires. We do not yet know very much about these effects, in part because most of the studies to date have assumed very large attacks on cities. However, the impact on the global climate apparently would be less than in large attacks on cities; but it may still be substantial enough to concern us.

In postulating nuclear winter scenarios we must invariably make some basic assumptions about national defense strategy and the role of nuclear weapons in that strategy. Needless-to-say, analysts often hold different beliefs and assumptions. Some will argue that a limited nuclear war in which cities are avoided or largely avoided is unrealistic; that once any nuclear weapons are used escalation to a very large scale nuclear war would be automatic. I do not agree, but if this were true we could stop worrying about nuclear winter. As I have already suggested, the direct effects would overwhelm the climatic effects. (Perhaps we should worry nevertheless about the effects on the climate of the Southern Hemisphere, but this is quite another matter and one on which there is very little solid data so far.)

I think a limited nuclear war is possible because all parties involved will have a very strong interest in keeping it limited. They may find it impossible to do so; I shall address that question below. The United States has certainly made plans to limit use of nuclear weapons and to control escalation. We have reason to believe that the Soviet Union, while expressing public skepticism about limiting nuclear war, has capabilities and plans which would permit them to do so.

Some observers also argue that planning to limit a nuclear war is dangerous because it leads to acceptance of the possibility of such a war. The possibility does exist, however remote, but it seems to me far worse to have no plans to control escalation or terminate a conflict before it becomes a total holocaust. I would be deeply disturbed and angry if my government did not have such plans. This does not mean that I am confident such plans will work. But it seems to me to be beyond argument that we are better off having such plans than having no options save surrender or all-out war. More important, every President and Secretary of Defense who has had to live with the responsibility for nuclear weapons seems to have arrived at the same conclusion.

If we are to concentrate on limited nuclear war scenarios and on climatological outcomes in which the decline in temperature is less pronounced and less prolonged than in the extreme cases, then it is appropriate to ask whether our plans and our weapons systems have adequately taken into account these phenomena. Unfortunately, I cannot go into nuclear plans in any detail in this forum, nor am I the appropriate person to do so. However, I would point out that U.S. planners have had to be concerned for some time (long before nuclear winter became a prominent issue) with so-called collateral effects, that is unintended damage to targets that were not the objective of a particular attack. That damage might be direct (e.g., from blast) or indirect (e.g., from fallout). Plans have been made and weapons have been designed for many years to minimize these effects, including the possibility of withholding attacks in certain instances. Now I want to be clear that it is not possible to conduct a war (with nuclear or nonnuclear weapons) without creating unintended damage. Wars are just too destructive and too unpredictable to expect that. But it is possible to minimize such unintended damage, and that can make a very substantial differrence.

One way that we have tried to do that over the years is by making our nuclear weapons smaller and more accurate. In the future it may be possible to make nonnuclear weapons that can do some of the jobs now done by nuclear weapons, and I believe it is important that we press ahead to try to do that, although I do not believe that we can ever hope to substitute fully nonnuclear for nuclear weapons simply by pressing technology. Thus, we ought also to continue development of nuclear weapons that create less unwanted damage. There are some possibilities here as well, in addition to continued improvements in accuracy, which should enable us to make weapons smaller. For example, one development is the earth-penetrating weapon, which can create substantial ground shock but little or no atmospheric effects. I think that weapon ought to receive more attention than it has, given the current concern with nuclear winter.

I have said that our plans do seek to minimize collateral damage as a result of the way that we target weapons. It would seem prudent, as we learn more about the effects of nuclear winter, that the appropriate authorities reexamine those plans, and adjust them if that is necessary, to take account of these effects.

Some commentators have suggested that the best way to assure that we never have nuclear winter is to reduce the levels of nuclear weapons below the threshold at which such effects could occur. I consider such an approach to be impractical. First, we do not know where that threshold lies today and are unlikely to know with any confidence for years if ever. Second, unless we are to reduce our weapons inventories unilaterally (a course of action which most arms control experts, myself included, would reject as dangerous and ineffective) we are talking about undertaking a diplomatic task that has defied our best efforts at negotiation for more than two decades. I am not suggesting that negotiated reductions are impossible or that we should abandon efforts to achieve such reductions, but given the past record, I do maintain that we need to consider other alternatives. I believe these lie in continuing our past efforts to make our weapons more discriminate and our plans more flexible. Not only will this reduce the prospects of a nuclear winter should nuclear weapons ever be used, it also is the best way to strengthen deterrence, for a force whose use is plausible is a far better deterrent than one whose use would be suicidal.

In sum, my conclusions are as follows:

Phenomena associated with "Nuclear winter" constitute potential collateral effects that should be examined seriously.

More attention should be given to the worldwide climatic effects of more limited attacks and "mild" nuclear winter.

There are things we can do, if this appears necessary, to minimize nuclear winter effects through the design of weapons and the adjustment of war plans.

Chairman **GOLDWATER**. Thank you very much, Mr. Sloss.

Now we have our final witness, Dr. Leon Goure, Director for the Center for Soviet Studies at Science Applications International Corporation.

Dr. Goure, welcome to the committee.

STATEMENT OF LEON GOURE, DIRECTOR OF THE CENTER FOR SOVIET STUDIES, SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

Dr. **GOURE**. Thank you, Senator Goldwater and gentlemen, I appreciate the opportunity to appear before this committee.

I must emphasize that my remarks are based entirely on personal views and on personal research. I have been a longtime student of Soviet views on the consequences of nuclear attacks and also of measures to mitigate their consequences.

Now, there are many factors to the so-called nuclear winter issue. One of these is both the scientific and the political-strategic interests of the Soviet Union in nuclear winter.

Of interest is the question of Soviet research and uses of the nuclear winter hypothesis. This specifically concerns the question whether the Soviet research has independently confirmed western nuclear winter findings and projections and also whether Soviet assessment of nuclear winter effects has influenced Soviet views on nuclear war on or deterrence as some people in the West have hoped would be the case.

Concerning the first question, it should be noted that in public Soviet statements, the Soviets have wholeheartedly endorsed the nuclear winter hypothesis and have claimed that their research independently confirms the worst case predictions of Western nuclear winter studies that were published in 1982 and 1983. However, a careful analysis of Soviet publications, conference papers and speeches of Soviet scientists show that in fact Soviet scientists have made no significant or independent contributions to the study of nuclear winter. Actually, study of nuclear winter is treated as an international effort at the present time.

What Soviet scientists have done in their public presentations is to uncritically borrow from western studies the most extreme assumptions, scenarios and values of critical parameters of fire, smoke and soot produced by nuclear detonations and applied them to crude models of global atmospheric circulation developed in part on the basis of obsolete Western models.

Particularly this has been the case of the Aleksandrov-Stenchikov model developed by the Computing Center of the U.S.S.R. Academy of Sciences which was published in English in 1983 and which has been widely publicized in the West.

One can only conclude that the claimed independent Soviet confirmation of the nuclear winter hypothesis in reality consists of little more than a playback of western research findings and research assumptions.

Indeed, as far as the public aspect of the Soviet nuclear winter research is concerned, there appears to be little reason to expect any significant Soviet contribution. This is so because Soviet scientists must conform in their statements to Soviet political objectives, because there are no war scenarios approved for public discussion in the Soviet Union and there is no permitted reconstruction or imaging of consequences of war for the Soviet Union, and also because Soviet computers, even those at the prestigious Computer Center of the U.S.S.R. Academy of Sciences, are acknowledged by Soviet scientists to lack the capability to model the increased complexities of nuclear winter research.

As a result, after 1983 the Soviets have not developed any computer models of the nuclear winter effects.

In addition, one of their stars in this affair, Dr. Aleksandrov, disappeared under mysterious circumstances in Madrid, Spain, on March 31, 1985.

Soviet scientists have also failed to respond to various requests from American scientists or Western scientists for data which they were thought to have, based on their atmospheric nuclear tests up to 1963 and from large forest fires.

While Soviet scientists have failed to independently support nuclear winter, it is clear that the Soviets have seen in this hypothesis a major propaganda opportunity to be exploited by the Soviet peace campaign to influence Western public opinion.

Already, in May 1983, Politburo candidate member, Boris Ponomarev, made clear to the Soviet scientific community that because of what he called the special public credibility of scientists, it is their "duty", as he put it, to inform the free world public about the consequences of nuclear war and the threat posed to world peace by U.S. defense policies and strategic concepts including the concept of limited nuclear war.

Thus, while the general Soviet public has been told very little specifically about the nuclear winter hypothesis and its effects (in fact, the much-touted Aleksandrov study has never been published in the Russian language), in their statements to foreign audiences, the Soviet scientists have consistently promoted the most dire predictions of nuclear war, including nuclear winter. They have ignored the changing findings of Western researchers which have tended to significantly mitigate the earlier predictions of the severity and likely duration of nuclear winter effects. Indeed, on July 28, 1985, an article in the Soviet Government newspaper "Izvestiya" calls all scientists whose findings indicate that nuclear winter effects may be less severe and of shorter duration than originally predicted, to be "obscurantists."

It can be said that the Soviet nuclear winter campaign has reaped considerable success because of its access to the Western media, Western public and scientific community, and the endorsement it has provided to the so-called Western antinuclear movement.

As to the second question, there is no evidence that the publicized Soviet Western views of nuclear winter have in any way influenced the Soviet leadership views of nuclear war or warfighting or defense policies.

The Soviet government continues to promote the value of civil defense measures and the need to further build up Soviet strategic forces. The Soviet military leadership has ignored the nuclear winter hypothesis altogether.

In his monograph, "History Teaches Vigilance," published in the spring of 1985, Marshal of the Soviet Union, N. V. Ogarkov, writes that Soviet military doctrine posits that a world war would be unprecedented in its scope, fierceness, and destructiveness. But then he goes on to say, that according to this doctrine, the war "will continue until total victory over the enemy is achieved."

In the Soviet compulsory civil defense instruction program for the general population, Soviet instructors were told in the summer of 1984 that while Soviet scientists and spokesmen were spreading the truth about the consequences of a nuclear war abroad, the instructors should not frighten the Soviet people when discussing the effects of nuclear weapons.

Soviet scientists, like their Western counterparts, acknowledge that the nuclear winter hypothesis is fraught with many uncertainties. In their most recent publications, they expressed greater concern about the possible depletion of the ozone layer as a result of nuclear detonations than about nuclear winter.

Judging from Soviet concept of warfighting and the programs to enhance the war survival of the Soviet Union, it would appear the Soviets are less likely to be concerned or worried about the severity of a nuclear winter than about its duration. This is so because the Soviets are concerned about the possibility of post-attack reconstitution of essential agricultural production.

To date, nuclear winter research has not seriously addressed the question of the possible duration of nuclear winter effects associated with various nuclear exchange scenarios. Generally speaking, research is focused on the first few months or few weeks after an attack. It has not seriously looked at what happens to the next growing season or next 6 months or year after a nuclear exchange. And, therefore, the Soviets do not have an answer to this question. Given the apparent constraint on Soviet research capabilities, they may have to depend for an answer to this question on the work of Western scientists.

It is important to keep in mind that Soviet discussions of possible consequences of a nuclear war addressed to Western audiences are intended to serve Soviet political objectives and, therefore, they do not necessarily reflect the actual views of the Soviet leadership or even of the Soviet scientific community. It is also important to remember that there is no private scientific research and no nongovernmental controlled scientific publications in the Soviet Union and also that the scientists allowed to travel and speak abroad, in effect, are Soviet officials specifically authorized to make screened and approved presentations.

Thank you very much.

[The prepared statement of Dr. Leon Goure follows:]

PREPARED STATEMENT OF DR. LEON GOURE,* DIRECTOR, CENTER FOR SOVIET STUDIES, SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

SOVIET "NUCLEAR WINTER" RESEARCH AND ITS IMPLICATIONS

Soviet views and research on the so-called "nuclear winter" hypothesis are of interest for two reasons. First, there is the question of whether independent Soviet research has confirmed or validated the findings of "nuclear winter" research conducted in the West. Second, there is the question whether the "nuclear winter" hypothesis, presumably based on Soviet research, has in any way influenced the views of the Soviet political and military leadership on nuclear war and warfighting concepts.

Concerning the first question, it should be noted that, to a significant extent, research into the "nuclear winter" phenomenon has been and continues to be an international effort in which some Soviet scientists have participated. Publicly, especially in Western forums, Soviet scientists have wholeheartedly embraced the "nuclear winter" hypothesis and have claimed that their research independently confirms the worst "nuclear winter" predictions of their Western colleagues. In fact, however, an examination of published Soviet research and of papers by Soviet scientists presented in international forums shows—as I have endeavored to demonstrate in my article " 'Nuclear Winter' in Soviet Mirrors" published in the Summer issue of *Strategic Review*—that this is not the case. Instead there is ample evidence that the Soviet Union has seen in the "nuclear winter" hypothesis primarily a major propaganda opportunity to be exploited in support of the so-called Soviet "peace" propaganda campaign. A leading role in this exploitation has been assigned to a number of Soviet scientist-spokesmen with wide contacts in the Western scientific community.

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* The following discussion represents the personal views of the author and of research conducted by him. It should not be taken as necessarily reflecting the views of the Science Applications International Corporation or of any other members of its staff.

From a scientific standpoint, Soviet scientists have made little, if any, meaningful contribution to the study of "nuclear winter." In nearly all cases, their papers and presentations have uncritically borrowed the "worst-case" war scenarios, assumptions about weapon laydowns and targets, and aggregate megatonnage detonated, as well as the values of critical parameters of dust, smoke and soot generated by the detonations and fires from Western studies, and have applied these to crude models of global atmospheric circulation. Such a "playback" of Western data, calculations and assumptions cannot be considered to provide an independent confirmation by Soviet scientists of Western findings.

A case in point is the widely publicized model of the global "nuclear winter" effect by Dr. V. Aleksandrov and Dr. G. Stenchikov of the Computing Center of the USSR Academy of Sciences. Both are mathematicians. They initially presented their findings in August 1983 at an international conference in Italy and then published them in September 1983, in English, in a pamphlet entitled "On the Modelling of the Climatic Consequences of the Nuclear War." An examination of this paper and of subsequent statements by Aleksandrov and by his superior in the Computing Center, Dr. N. Moiseyev, shows that all the key data inputs to their model were taken from Western studies, i.e., a paper by Dr. P.J. Crutzen and Dr. J.W. Birks published in 1982 in the Swedish journal *Ambio*, and a study by R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack and C. Sagan, often referred to as TTAPS, published in 1983. Although the TTAPS study findings were not published until December 1983, Aleksandrov, as he acknowledged, was able to obtain them when he attended a preliminary review seminar held in Cambridge, Massachusetts, in April 1983. As to the model of global atmospheric circulation used by Aleksandrov-Stenchikov, it was developed on the basis of a two-level Mintz-Arkawa model, published by the Rand Corporation (Santa Monica, CA), in 1971 and now considered to be obsolete. Furthermore, in their computations, Aleksandrov-Stenchikov used the "worst-case" TTAPS scenario, which assumed a 10,000 megaton nuclear exchange rather than the TTAPS or Ambio baseline scenarios. Even then, the claimed climatic effects implied the introduction into the atmosphere of far greater amounts of smoke and soot than has been estimated by the Western studies using a similar scenario. In private conversations, Aleksandrov acknowledged that he was not qualified to assess the values of the critical parameters of the "nuclear winter" hypothesis, nor able to provide any independent Soviet data and calculations concerning them. In March 1985, while on a lecture tour in Spain, Aleksandrov disappeared under mysterious circumstances in Madrid and has not been heard from since. Some people surmise that he has either been kidnapped or killed by the KGB because he had too freely expressed doubts about the validity of his "nuclear winter" findings.

There are several reasons for the failure of Soviet scientists to make any significant contributions to international "nuclear winter" research.

First, public statements by Soviet scientists on the possible consequences of a nuclear war cannot be independent or objective, but must be in accord with the Soviet Union's political objectives and approved line.

Second, there is no public discussion in the Soviet Union of alternate possible nuclear war scenarios and their implications. Soviet scientists, therefore, are unable—at least in public—to cite and use an independent Soviet war scenario. Instead, they must use those described in the West. Even then, for political and propaganda purposes, they nearly always uncritically use Western "worst-case" scenarios regardless of their credibility.

Third, unlike in the West, there is no public discussion or assessment of the possible consequences of a nuclear war for the Soviet Union itself. No maps showing hypothetical targets and fallout patterns in the Soviet Union have ever been published, nor are there estimates of possible Soviet casualties associated with various war scenarios. When discussing the consequences of a nuclear war, Soviet scientists either generalize on the basis of global effects or cite Western estimates of such effects for the United States alone.

Fourth, there are growing indications that Soviet computers, even those at the prestigious Computing Center of the USSR Academy of Sciences, are not sufficiently powerful and technologically advanced to be of use for work on the increasingly more complex "nuclear winter" models. Indeed, unlike American scientists, Soviet scientists have not produced any new computer models of the global "nuclear winter" effects since 1983. Soviet scientists have acknowledged that they lack the computer capacities and instruments to model mass fires and to conduct large fire experiments. It is not surprising, therefore, that Soviet scientists have failed to respond to requests by Western scientists, notably by Dr. Carl Sagan, for data derived from Soviet atmospheric nuclear tests before 1963, from large forest fires, or concerning Soviet views on likely war scenarios.

Of course, Soviet public duplication of Western "nuclear winter" scenarios, data and findings does not preclude the possibility that Soviet scientists are engaged in classified research on this subject. It is important to keep in mind that there is no private research conducted in the Soviet Union and no non-government controlled scientific publications, and that Soviet scientists appearing in foreign forums are not private individuals but, in effect, Soviet state officials who are authorized to do so for specific purposes of the Soviet government. Officially, unlike the U.S. government, the Soviet government is not conducting a research program into "nuclear winter."

It should be noted that, while for the past two years Soviet scientists have not made any notable contribution to "nuclear winter" research, they have continued to focus on other potential effects of a nuclear war, such as the depletion of the ozone layer and also the cooling effects of nitric dioxide (NO_2) generated by nuclear detonations. The latter phenomenon is said to be derived from observations by Soviet scientists made during Soviet atmospheric nuclear tests up to 1963. However, these possible effects are not-significantly related to the "nuclear winter" phenomenon and have been studied by American scientists in the 1960s and 1970s.

While Soviet science has failed to independently support the "nuclear winter" hypothesis and its predictions, Soviet propaganda aimed at the West has sought to exploit this hypothesis. Indeed, Politburo candidate Boris Ponomarev gave the scientists their marching orders at an officially sponsored "All-Union Conference of Scientists for Ridding Humanity of the Threat of Nuclear War, for Disarmament and Peace" convened in Moscow in May 1983. According to Ponomarev, it is the "duty" of scientists to "disclose to humanity," i.e., people outside the communist bloc, "all the truth about the consequences of a nuclear war," and the dangers of the U.S. concept of a "limited" nuclear war, to show that the United States is the main source of a possible nuclear war, and so on. One result of this conference was the organization of a Committee of Soviet Scientists for Peace and Against the Nuclear Threat, with Academician Ye.P. Velikhov, a vice president of the USSR Academy of Sciences, elected as its chairman. Obviously, this committee had the full approval of the Soviet leadership and, as Ponomarev indicated, was expected to duplicate the propaganda gains won earlier by Soviet physicians, members of International Physicians for the Prevention of a Nuclear War, organized in 1980, with the participation of the American organization, Physicians for Social Responsibility.

What is important to note about the Soviet propaganda exploitation of the "nuclear winter" hypothesis is that it was and continues to be primarily aimed at the Free World. Relatively little specific information on "nuclear winter" has been made available to the general public in the Soviet Union. For example, the TTAPS study has not been published in the Soviet Union in Russian translation, nor, interestingly enough, has the Aleksandrov-Stenchikov study.

Generally the Soviet press has given little space to the discussion of possible consequences of a nuclear war, including the findings presented at scientific conferences held in the Soviet Union and abroad. By contrast, Soviet scientists have been very active in promoting "worst-case" predictions of the consequences of a nuclear war in their publications, conference papers, speeches, and interviews aimed at Western audiences. In so doing, they have ignored the changing findings of Western scientists which have tended to significantly mitigate the earlier, most dire predictions of "nuclear winter" effects. The Soviet press has failed to take notice of the National Research Council report on The Effects on the Atmosphere of a Major Nuclear Exchange, which was published in January 1985, or the NRC-sponsored symposium on "Nuclear Winter": Current Assessment and Implications" held at the National Academy of Sciences in March 1985. Instead, an article in the July 28, 1985, issue of the Soviet newspaper Izvestiya declares that all scientists, whose findings indicate that because of scavanging of the smoke and soot the "nuclear winter" effect may be less severe and of relatively shorter duration than previously predicted, to be "obscurantists." Typically, in their publications addressed to foreign audiences, such as a 1984 pamphlet entitled Global Consequences of Nuclear War and Developing Countries, the Soviets have continued to cite Aleksandrov-Stenchikov, Crutzen-Birks, and TTAPS as their sources for their description of the worst possible "nuclear winter" effects, even though new data shows them to be unrealistic.

There is also no evidence that the publicized Soviet views on "nuclear winter" have had any influence on the Soviet political and military leadership's views on nuclear war, strategy and warfighting. Initially, some American scientists had hoped that because of the public Soviet endorsement of the "nuclear winter" hypothesis and the access that senior Soviet scientists have to top Soviet political and military leaders, the leadership would take into account the mutual deterrent effects of a possible "nuclear winter." Unfortunately, there is no indication of this.

Publicly, the Soviets have continued to promote the value of Soviet civil defense measures, the need to further build up Soviet strategic forces, and the importance of the continuing contribution by scientists to Soviet defense efforts. The Soviet military leadership has simply ignored the "nuclear winter" hypothesis altogether. In his monograph History Teaches Vigilance, published in the Spring of 1985, Marshal of the Soviet Union N.V. Ogarkov writes that Soviet military doctrine posits that a world war would be unprecedented in its scope, fiereeness and destructiveness and that it "will continue until total victory over the enemy is attained." At the same time, Soviet civil defense instructors, in the compulsory program of civil defense instruction of the Soviet population, have been told that in their description of nuclear weapon effects they should avoid frightening the population. Of course, the opposite of this rule applies when Soviet propagandists—be they scientists or political commentators—address foreign audiences.

Soviet scientists, like their Western counterparts, have publicly acknowledged that the "nuclear winter" hypothesis is fraught at this time with many uncertainties. They also recognize that the severity, duration, and consequences of a "nuclear winter" are largely scenario dependent, including the time of the year when the nuclear exchange occurs. The Soviets are aware that as far as the belligerent countries are concerned the prompt effects and local radioactive fallout from nuclear detonations, as well as the extent of damage to the economy, are likely to be of greater significance than a relatively short "nuclear winter" effect, regardless of its severity. Of course, Soviet scientists—like their Western counterparts—recognize that a nuclear war between the major powers may severely affect the availability of food and medical supplies in neutral countries, especially less developed ones, regardless of whether or not they are subjected to a "nuclear winter."

One problem which appears to concern the Soviets is the question of the feasibility of post-attack reconstitution of essential agricultural production, that is to grow food crops the next planting season six months to a year after the attack. The Soviets expect to lose most of their standing crops at the time of the nuclear exchange to local radioactive fallout, regardless of any damage from a "nuclear winter" effect. They anticipate being able to feed the surviving population from food stocks and surviving livestock until the next harvest, and have an elaborate program for the post-attack reconstitution of agricultural production and the protection of agricultural resources. Thus, the significant issue for the Soviet Union is not so much the severity of a "nuclear winter" effect but its probable duration.

To date, "nuclear winter" research has not seriously examined the likely duration of "nuclear winter" effects associated with various war scenarios. Some scientists see the possibility of a short, largely localized atmospheric chill, while others see the possibility of a more severe and protracted decline in air temperatures. Of course, it must be noted that the scenarios which generate such declines in temperature also postulate a major reduction in the population as a result of the attack, thus leading to a reduced demand for food to sustain the survivors. Given the difficulties Soviet scientists appear to have in studying "nuclear winter," it may well be that they will not be able to independently answer the questions concerning the duration of the "nuclear winter" effects and will have to depend for such answers on the conclusions reached by Western scientists.

Chairman **Goldwater**. Thank you very much, Doctor.

Without objection, I would like to place in the record a paper on this subject by the Department of Defense, "Potential Effects of Nuclear War on the Climate."

[The information follows:]

The Secretary of Defense,
Washington, DC, March 1985.

Hon. Barry Goldwater,
Chairman, Committee on Armed Services, U.S. Senate,
Washington, DC.

Dear Mr. Chairman: The attached report is submitted to the Committee on Armed Services in response to the provisions of the Department of Defense Authorization Act, 1985, the Committee of Conference. The report delineates the technical issues surrounding the potential effects of nuclear war on the climate, provides a brief history of its evolution, describes DOD's early through current participation, and examines our nuclear policy in light of the technical evidence presented thus far.

Sincerely,

Caspar Weinberger.

Attachment.

SECRETARY OF DEFENSE

CASPAR W. WEINBERGER

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

THE POTENTIAL EFFECTS OF NUCLEAR WAR ON THE CLIMATE

A REPORT TO THE UNITED STATES CONGRESS

MARCH 1985

PREFACE

This report to the Congress on the potential climatic effects of nuclear war has been prepared to satisfy provisions contained in Section 1107 of the Department of Defense Authorization Act, 1985, Committee of Conference, as follows:

> "Sec. 1107 (a) The Secretary of Defense shall participate in any comprehensive study of the atmospheric, climatic, environmental, and biological consequences of nuclear war and the implications that such consequences have for the nuclear weapons strategy and policy, the arms control policy, and the civil defense policy of the United States.
>
> (b) Not later than March 1, 1985, the Secretary of Defense shall submit to the Committees on Armed Services of the Senate and House of Representatives an unclassified report suitable for release to the public, together with classified addenda (if required), concerning the subject described in subsection (a). The Secretary shall include in such report the following:
>
> > (1) A detailed review and assessment of the current scientific studies and findings on the atmospheric, climatic, environmental, and biological consequences of nuclear explosions and nuclear exchanges.
> >
> > (2) A thorough evaluation of the implications that such studies and findings have on (A) the nuclear weapons policy of the United States, especially with regard to strategy, targeting, planning, command, control, procurement, and deployment, (B) the nuclear arms control policy of the United States, and (C) the civil defense policy of the United States.
> >
> > (3) A discussion of the manner in which the results of such evaluation of policy implications will be incorporated into the nuclear weapons, arms control, and civil defense policies of the United States.
> >
> > (4) An analysis of the extent to which current scientific findings on the consequences of nuclear explosions are being studied, disseminated, and used in the Soviet Union."

This focus of this report deals with the atmospheric and climatic effects of nuclear war, and does not deal with other effects which could have environmental or biological consequences. Other effects, both the horrible immediate devastation, and long-term effects such as widespread fallout or ionospheric chemistry perturbations, have been dealt with previously. Moreover, the newly postulated climatic effects, at the possible upper extremes indicated by some analyses, would probably surpass these better understood effects.

On past occasions when other more immediate kinds of global effects have been under active assessment--and there have been several such episodes over the years--it took some time for their magnitude and implications to be assessed. This will also be true for the current issue of climatic effects. And in each previous case, the conclusion was drawn that, even were the effect to have been very widespread and very severe, the most basic elements of our policy remain sound: nuclear war must and can be prevented, and to accomplish this imperative, the United States must maintain a strong deterrent capability. This requirement remains true today. Moreover, there are two further considerations which bear on the issue of global effects of nuclear war and our deterrent policy. First, we believe the prospects are promising for significant reductions in offensive weapons. Second, strategic defense offers a path to reduce, and perhaps someday eliminate, the threat of nuclear devastation.

The report commences with a review of the current understanding of the technical issues, and then describes the implications of that understanding, concluding with a description of Soviet activities concerning the analysis of the phenomena.

THE POTENTIAL EFFECTS OF NUCLEAR WAR ON THE CLIMATE
A REPORT TO THE UNITED STATES CONGRESS

1. Technical Issues

The Climatic Response Phenomena: The basic phenomena that could lead to climatic response may be described very simply. In a nuclear attack, fires would be started in and around many of the target areas either as a direct result of the thermal radiation from the fireball or indirectly from blast and shock damage. Examples of the latter would be fires started by sparks from electrical short circuits, broken gas lines and ruptured fuel storage tanks. Such fires could be numerous and could spread throughout the area of destruction and in some cases beyond, depending on the amount and type of fuel available and local meteorological conditions. These fires might generate large quantities of smoke which would be carried into the atmosphere to varying heights, depending on the meteorological conditions and the intensity of the fire.

In addition to smoke, nuclear explosions on or very near the earth's surface can produce dust that would be carried up with the rising fireball. As in the case of volcanic eruptions such as Mt. Saint Helens, a part of the dust would probably be in the form of very small particles that do not readily settle out under gravity and thus can remain suspended in the atmosphere for long periods of time. If the yield of the nuclear explosion were large enough to carry some of the dust into the stratosphere where moisture and precipitation are not present to wash it out, it could remain for months.

Thus, smoke and dust could reach the upper atmosphere as a result of a nuclear attack. Initially, they could be injected into the atmosphere from many separate points and to varying heights. At this point, several processes would begin to occur simultaneously. Over time, circulation within the atmosphere would begin to spread the smoke and dust over wider and wider areas. The circulation of the atmosphere would itself be perturbed by absorption of solar energy by the dust and smoke clouds, so it could be rather different from normal atmospheric circulation. There may also be processes that could transport the smoke and dust from the troposphere into the stratosphere. At the same time, the normal processes that cleanse pollution from the lower-and middle-levels of the atmosphere would be at work. The most obvious of these is precipitation or washout, but there are several other mechanisms also at work. While this would be going on, the physical and chemical characteristics of the smoke and dust could change so that, even though they are still suspended in the atmosphere, their ability to absorb or scatter sunlight would be altered.

Depending upon how the atmospheric smoke and dust generated by nuclear war are ultimately characterized, the suspended particulate matter could act much like a cloud, absorbing and scattering sunlight at high altitude and reducing the amount of solar energy reaching the surface of the earth. How much and how fast the surface of the earth might cool as a result would depend on many of the yet undetermined details of the process, but if there is sufficient absorption of sunlight over a large enough area, the temperature change could be significant. If the smoke and dust clouds remained concentrated over a relatively small part of the earth's surface, they might produce sharp drops in the local temperature under them; but the effect on the hemispheric (or global) temperature would be slight since most areas would be substantially unaffected.

However, the natural tendency of the atmosphere, disturbed or not, would be to disperse the smoke and dust over wider and wider areas with time. One to several weeks would probably be required for widespread dispersal over a region thousands of kilometers wide. Naturally, a thinning process would occur as the particulate matter spread. At the end of this dispersal period, some amount of smoke and dust would remain, whose ability to attenuate and/or absorb sunlight would depend on its physical and chemical state at the time. By this time, hemispheric wide effects might occur. Temperatures generally would drop and the normal atmospheric circulation patterns (and normal weather patterns) could change. How long temperatures would continue to drop, how low they would fall, and how rapidly they would recover, all depend on many variables and the competition between a host of exacerbating and mitigating processes.

Uncertainties also pervade the question of the possible spread of such effects to the southern hemisphere. Normally the atmospheres of the northern and southern hemispheres do not exchange very much air across the equator. Thus, the two hemispheres are normally thought of as being relatively isolated from one another. However, for high enough loading of the atmosphere of the northern hemisphere with smoke and dust, the normal atmospheric circulation patterns might be altered and mechanisms have been suggested that would cause smoke and dust from the northern hemisphere to be transported into the southern hemisphere.

There is fairly general agreement, at the present time, that for major nuclear attacks the phenomena could proceed about as we have described, although there is also realization that important processes might occur that we have not yet recognized, and these could work to make climatic alteration either more or less serious. However, the most important thing that must be realized is that even though we may have a roughly correct qualitative picture, what we do not have, as will be discussed later, is the ability to predict the corresponding climatic effect quantitatively; significant uncertainties exist about the magnitude, and persistence of these effects. At this time, for a postulated nuclear attack and for a specific point on the earth, we cannot predict quantitatively the materials which may be injected into the atmosphere, or how they will react there. Consequently, for any major nuclear war, some decrease in temperature may occur over at least the northern mid-latitudes. But what this change will be, how long it will last, what its spatial distribution will be, and, of much more importance, whether it will lead to effects of equal or more significance than the horrific destruction associated with the short-term effects of a nuclear war, and the other long-term effects such as radioactivity, currently is beyond our ability to predict, even in gross terms.

Historical Perspective: New interest in the long-term effects on the atmosphere of nuclear explosions was raised in 1980 when scientists proposed that a massive cloud of dust caused by a meteor impact could have led to the extinction of more than half of all the species on earth. The concept of meteor-impact dust affecting the global climate led to discussions at the National Academy of Sciences (NAS) in 1981. In April 1982, an ad hoc panel met at the Academy to assess the technical aspects of nuclear dust effects. At the meeting, the newly-discovered problem of smoke was brought up. The potential importance of both smoke and dust in the post-nuclear environment was recognized by the panel, who wrote a summary letter recommending that the Academy proceed with an in-depth investigation. In 1983, the Defense Nuclear Agency agreed to sponsor this investigation, on behalf of the Department of Defense. The results were published in the National Research Council report "The Effects on the Atmosphere of a Major Nuclear Exchange," released in December 1984.

Appreciation of smoke as a major factor resulted from the work of Crutzen and Birks. In 1981, Ambio, the Journal of Swedish Academy of Sciences, arranged a special issue on the physical and biological consequences of nuclear war. Crutzen was commissioned to write an article on possible stratospheric ozone depletions. He and Birks extended their analysis to include nitrogen oxides (NO_x) and hydrocarbon air pollutants generated by fires. Arguing from historical forest fire data, they speculated that one million square kilometers of forests might burn in a nuclear war. They estimated very large quantities of smoke would be produced as a result. Subsequent evaluations based upon hypothetical exchanges have yielded much smaller burned areas and smoke production. Nevertheless, their work provided insight and impetus for subsequent studies.

The first rough quantitative estimates of the potential magnitude of the effects of nuclear war on the atmosphere were contained in a paper published in Science in December 1983(1) generally referred to as TTAPS, an acronym derived from the first letter of the names of the five authors. This study estimated conditions of near-darkness and sub-freezing land temperatures, especially in continental interiors, for up to several months after a nuclear attack--almost independent of the level or type of nuclear exchange scenario used. TTAPS suggested that the combination of all of the long-term physical, chemical, and radiobiological effects of nuclear explosions could, on a global scale, prove to be as serious or more serious than the immediate consequences of the nuclear blasts, although no specific damage or casualty assessments were carried out for either the immediate effects or the effects of the postulated climatic changes.

While the Crutzen and Birks studies stirred some interest in scientific circles, the TTAPS study, and its widespread dissemination in various popular media, brought the problem to wide public attention. Because of its widespread dissemination, it is important to review this work in detail, and, because the salient feature of our current understanding is the large uncertainties, we will begin by discussing the nature of the uncertainties, using the TTAPS study as a vehicle for the discussion.

Uncertainties: The model used in the TTAPS study was actually a series of calculations that started with assumed nuclear exchange scenarios and ended with quantitative estimate of an average hemispheric temperature decrease. Since these phenomena are exceedingly complex and outside the bounds of our normal experience, one is forced to employ many estimates, approximations, and educated guesses to arrive at quantitative results. To appreciate the significance of the predictions derived from the TTAPS model, it is necessary to understand some of its features and limitations.

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(1) Turco, R. P. et al.; Nuclear Winter: Global Consequences of Multiple Nuclear Explosions; Science, 23 December 1983, VOL 222, Number 4630.

Looked at most broadly, there are three phases to the modeling problem: the initial production of smoke and dust; its injection, transport, and removal within the atmosphere; and the consequent climatic effects.

In the TTAPS model, the amount of smoke initially produced for any given scenario was probably the most uncertain parameter. This is because a large number of poorly-known variables were combined to determine the amount of smoke that could be produced from any single nuclear explosion. In actuality, the same yield weapon could produce vastly different amounts of smoke over different target areas and under different meteorological conditions. Some of the factors that must be considered--although not taken into account in the TTAPS study--include: the thermal energy required for ignition of the various fuels associated with a particular target area, the sustainability of such a fire, the atmospheric transmission and the terrain features which will determine the area receiving sufficient thermal energy from the fireball to cause ignition, the type and quantity of combustible material potentially available for burning, the fraction that actually burns, and finally, the amount of smoke produced per unit mass of fuel burned. Every target is unique with respect to this set of characteristics, and a given target may change greatly depending on local weather, season, or even time of day.

The TTAPS study did not attempt to analyze the individual targets or areas used for their various scenarios; rather, it made estimates of average or plausible values for all the parameters needed to satisfy the model. This procedure is not unreasonable and is consistent with the level of detail in the analysis, but the potential for error in estimating these averages is clearly quite large. In one case, a more detailed assessment of smoke production has recently been completed as a result of the ongoing DoD research in this area. Small and Bush(2) have made an analysis of smoke produced as a result of hypothetical non-urban wildfires which one can directly compare with the corresponding modeling assumption used in this TTAPS scenario. Bush and Small studied 3,500 uniquely located, but hypothetical targets, characterizing each according to monthly average weather, ignition area, fuel loading, fire spread, and smoke production. The results showed a significantly smaller smoke production--by a factor of over 30 in July to almost 300 in January--than comparable TTAPS results. An effort is underway to resolve this great difference. It is cited here to illustrate the very large current uncertainties in only one of several critically important parameters.

In the TTAPS analysis, smoke was more important than dust in many cases, and as a result popular interest has tended to focus on fires rather than dust. This may or may not be the correct view. If smoke is systematically overestimated, especially in scenarios that should emphasize dust production over smoke (such as attacks on silos using surface bursts), analytic results will be skewed. Additionally, uncertainties associated with the lofting of dust are large because of limited data from atmospheric nuclear tests carried out prior to 1963. This is because most tests were not relevant to the question of surface or near-surface bursts over continental geology, or the relevant measurements were not made. The range of uncertainty for total injected mass of submicron size dust, that which is of greatest importance, is roughly a factor of ten, based on our current knowledge.

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(2) Small, R.D., Bush, B. W.; Smoke Production from Multiple Nuclear Explosions in Wildlands; Pacific Sierra Research Corporation, in publication.

After generation of smoke and dust is estimated, a model must then portray its injection into the atmosphere, the removal processes, and the transport both horizontally and vertically. The TTAPS model did not directly address these processes since it is a one-dimensional model of the atmosphere. By one-dimensional, one means that the variation of atmospheric properties and processes are treated in only the vertical direction. There is no latitudinal or longitudinal variation as in the real world. A one-dimensional model can only deal with horizontally averaged properties of the entire hemisphere. Of great significance, the land, the oceans, and the coastal interface regions cannot be treated. This is a critical deficiency because the ocean, which covers almost three-fourths of the earth's surface, has an enormous heat capacity compared to the land and will act to moderate temperature changes, especially near coastlines and large lakes. The TTAPS authors did acknowledge this limitation and pointed out that these effects would lessen their predicted temperature drops.

Because there is no horizontal (latitude and longitude) dependence in a one-dimensional model, the extent to which smoke and dust would be injected into the atmosphere over time were not estimated in a realistic way. Instead, the total smoke and dust estimated for a given scenario was placed uniformly over the hemisphere at the start of their calculation. The most certain effect of all this is that the hemisphere average temperature drops very rapidly--much faster than it would in a more realistic three-dimensional model using the same input variables.

The one-dimensional model has other shortfalls. Recovery from the minimum temperatures would largely be accomplished through the gradual removal of smoke and dust, and it was assumed that this removal rate would be the same in the perturbed atmosphere as it is in the normal atmosphere. Even in the normal atmosphere, removal of pollutants is a poorly understood process. Most pollution removal depends on atmospheric circulation and precipitation, but in an atmosphere with a very heavy burden of smoke and dust, the circulation and weather processes may be greatly altered. Some potential alterations could lead to much slower removal than normal, others to more rapid removal. Currently we have little insight into this uncertainty.

This discussion of the deficiencies of the one-dimensional TTAPS model is not meant as a criticism. A one-dimensional model is a valuable research tool and can provide some preliminary insights into the physical processes at work. The three-dimensional models needed to treat the problem more realistically are exceedingly complex and will require very large computational resources. The DoD and Department of Energy, in conjunction with the National Center for Atmospheric Research (NCAR) and other agencies, are pursuing the development of three-dimensional models to treat the atmospheric effects problem. Our work is progressing, and the first results of this effort are now beginning to appear. Though very preliminary and not a complete modeling of any specific scenario, they suggest that:

- Substantial scavenging of smoke injected into the lower atmosphere from the continents of the Northern Hemisphere may occur as the smoke is being more widely dispersed over the hemisphere.

- Lofting of smoke through solar heating could act to increase the lifetime of the remaining smoke and may reduce the sensitivity to height of injection.

- For very large smoke injections, global-scale spreading and cooling are more likely in summer than in winter.

Despite good initial progress, many basic problems remain to be solved in the areas of smoke and dust injection, transport, and removal. In order to make the results produced by these models more accurate, we must improve our understanding of the basic phenomena occurring at the micro, meso, and global scale.

One final problem should be mentioned. Dust and smoke have differing potentials to effect the climate only because of their ability to absorb and scatter sunlight. The absorption and scattering coefficients of the various forms of smoke, dust, and other potential nuclear-produced pollutants must be known before any realistic predictions can be expected. Here again there is a large uncertainty, and what we do know about pollutants in the normal atmosphere may not be correct for the conditions in a significantly altered atmosphere.

National Academy of Sciences Report, 1984: Following their preliminary review of the possible effects of nuclear war-induced smoke and dust in April 1982, the NAS came to an agreement with DNA, acting on behalf of the DoD, to support a full-fledged study. The first committee meeting occurred at the NAS in March 1983. The NAS committee adopted the one-dimensional TTAPS analysis as a starting point for their investigation. During the course of the study, virtually all of the work going on pertinent to this phenomenon was reviewed.

The result of this effort was the NAS report, "The Effects on the Atmosphere of a Major Nuclear Exchange," released on December 11, 1984.

The conclusion of the report states that:

> ". . . a major nuclear exchange would insert significant amounts of smoke, fine dust, and undesirable species into the atmosphere. These depositions could result in dramatic perturbations of the atmosphere lasting over a period of at least a few weeks. Estimation of the amounts, the vertical distributions, and the subsequent fates of these materials involves large uncertainties. Furthermore, accurate detailed accounts of the response of the atmosphere, the redistribution and removal of the depositions, and the duration of a greatly degraded environment lie beyond the present state of knowledge.
>
> "Nevertheless, the committee finds that, unless one or more of the effects lie near the less severe end of their uncertainty ranges, or unless some mitigating effect has been overlooked, there is a clear possibility that great portions of the land areas of the northern temperate zone (and,

perhaps, a large segment of the planet) could be severely affected. Possible impacts include major temperature reductions (particularly for an exchange that occurs in the summer) lasting for weeks, with subnormal temperatures persisting for months. The impact of these temperature reductions and associated meteorological changes on the surviving population, and on the biosphere that supports the survivors, could be severe, and deserves careful independent study.

". . . all calculations of the atmospheric effects of a major nuclear war require quantitative assumptions about uncertain physical parameters. In many areas, wide ranges of values are scientifically credible, and the overall results depend materially on the values chosen. Some of these uncertainties may be reduced by further empirical or theoretical research, but others will be difficult to reduce. The larger uncertainties include the following: (a) the quantity and absorption properties of the smoke produced in very large fires; (b) the initial distribution in altitude of smoke produced in large fires; (c) the mechanism and rate of early scavenging of smoke from fire plumes, and aging of the smoke in the first few days; (d) the induced rate of vertical and horizontal transport of smoke and dust in the upper troposphere and atmosphere; (e) the resulting perturbations in atmospheric processes such as cloud formation, precipitation, storminess, and wind patterns, and (f) the adequacy of current and projected atmospheric response models to reliably predict changes that are caused by a massive, high altitude, and irregularly distributed injection of particulate matter. The atmospheric effects of a nuclear exchange depend on all of the foregoing physical processes ,(a) through (e)., and their ultimate calculation is further subject to the uncertainties inherent in (f)."

The Interagency Research Program (IRP): The genesis of this program stems from ongoing DoD and DoE research efforts. In 1983, both the DoD and the DoE started research on the atmospheric response phenomena. In addition to sponsoring the NAS study just discussed, the DoD portion of the program addressed a broad range of issues associated with the long-term global climatic effects of nuclear exchange. This program ($400K in FY83, $1100K in FY84, $1500K in FY85, $2500K in FY86 and continuing at appropriate levels into the future) supports research on several fronts--at numerous government laboratories, universities, and contractors.

The DoD portion of the IRP emphasizes research in (1) the smoke and dust source terms, including the definition of total ignition area, fuel loading and fire spreading, and particulate production, (2) large-scale fire characteristics, particulate lofting, scavenging, coagulation, rain-out, and atmospheric injection, (3) chemistry, including the chemical kinetics of fires and fireballs, the chemical consequences of mesoscale and global processes, and radiative properties (optical and infrared absorption, emission, and scattering), and (4) climatic effects, including the improvement of mesoscale and global climate models to incorporate better particulate source functions; horizontal advection processes; vertical mixing; solar radiation; particulate scavenging; inhomogeneities; particulate, radiative, and circulation feedbacks; seasonal differences; and particulate spreading.

The effort supported by the DoE is fully coordinated with that of the DoD and is currently funded at roughly $2M per year. The LLNL program is broad-based and includes modeling of urban fire ignition, plume dynamics, climate effects, radioactive fallout, and biological impacts. The LANL program focuses on developing comprehensive models for global-scale climate simulations. It is coordinated with complementary efforts at NCAR and NASA Ames. The IRP came into being with approval of the draft Research Plan for Assessing the Climatic Effects of Nuclear War prepared by a committee of university and government scientists. The plan was initiated by Presidential Science Advisor, Dr. George Keyworth, with the National Climate Program Office of NOAA heading the preparation effort. This program augments and coordinates the research activities currently underway in the DoD and the DoE with other government agencies. The program focuses particularly on the problems of fire dynamics, smoke production and properties, and mesoscale processes. The proposed additional research includes increases in theoretical studies, laboratory experiments, field experiments, modeling studies, and research on historical and contemporary analogues of relevant atmospheric phenomena.

The IRP recognizes the need for expertise from a number of experts inside and outside of the Federal Government--many are already at work on the problem. Participating government agencies would include the Department of Defense (DNA), Department of Energy, National Oceanic and Atmospheric Administration (NOAA), National Science Foundation (NSF), National Bureau of Standards, National Aeronautics and Space Administration (NASA), Federal Emergency Management Agency (FEMA), and the U.S. Forest Service. The IRP Steering Group is chaired by the President's Science Advisor and is composed of representatives from the Department of Defense, Department of Energy, Department of Commerce, and the National Science Foundation.

The major goals of the IRP are to accelerate the research to reduce the numerous uncertainties in smoke sources and to improve modeling of atmospheric effects. Although it is recognized that not all of the uncertainties could be reduced to uniform or perhaps even to acceptable levels, it is clearly possible to improve our knowledge of the climatic consequences of nuclear exchanges.

2. Summary Observations on the Current Appreciation of the Technical Issues

The Department of Defense recognizes the importance of improving our understanding of the technical underpinnings of the hypothesis which asserts, in its most rudimentary form, that if sufficient material, smoke, and dust are created by nuclear explosions, lofted to sufficient altitude, and were to remain at altitude for protracted periods, deleterious effects would occur with regard to the earth's climate.

We have very little confidence in the near-term ability to predict this phenomenon quantitatively, either in terms of the amount of sunlight obscured and the related temperature changes, the period of time such consequences may persist, or of the levels of nuclear attacks which might initiate such consequences. We do not know whether the long-term consequences of a nuclear war--of whatever magnitude--would be the often postulated months of subfreezing temperatures, or a considerably less severely perturbed atmosphere. Even with widely ranging and unpredictable weather, the destructiveness for human survival of the less severe climatic effects might be of a scale similar to the other horrors associated with nuclear war. As the Defense Science Board Task Force on Atmospheric Obscuration found in their interim report:

> "The uncertainties here range, in our view, all the way between the two extremes, with the possibility that there are no long-term climatic effects no more excluded by what we know now than are the scenarios that predict months of sub-freezing temperatures."

These observations are consistent with the findings in the NAS report, summarized earlier in this report. We believe the NAS report has been especially useful in highlighting the assumptions and the considerable uncertainty that dominate the calculations of atmospheric response to nuclear war. While other authors have mentioned these uncertainties, the NAS report has gone to considerable length to place them in a context which improves understanding of their impact.

We agree that considerable additional research needs to be done to understand better the effects of nuclear war on the atmosphere, and we support the IRP as a means of advancing that objective. However, we do not expect that reliable results will be rapidly forthcoming. As a consequence, we are faced with a high degree of uncertainty, which will persist for some time.

Finally, in view of the present and prospective uncertainties in these climatic predictions, we do not believe that it is possible at this time to draw competent conclusions on their biological consequences, beyond a general observation similar to that in the NAS report: if the climatic effect is severe, the impact on the surviving population and on the biosphere could be correspondingly severe.

3. Policy Implications

The issues raised by the possibility of effects of nuclear war on the atmosphere and climate only strengthen the basic imperative of U.S. national security policy--that nuclear war must be prevented. For over three decades, we have achieved this objective through deterrence and in the past 20 years we have sought to support it through arms control. Now, through the Strategic Defense Initiative, we are seeking a third path to reduce the threat of nuclear devastation.

In the remainder of this report, we will first discuss these three principal elements of our posture--deterrence, arms control, and the Strategic Defense Initiative--briefly describing each one and discussing how it relates to the issue of possible severe climatic effects. We conclude, in this regard, that these three elements, and the initiatives we are taking for each of them, remain fundamentally sound. We then explore the possibility of additional initiatives explicitly designed to mitigate climatic effects, concluding that, while some may be possible, the state of our technical understanding of these phenomena is not yet mature enough to have allowed development of specific initiatives. Finally, we review Soviet perceptions of climatic effects and their implications. We observe that Soviet perceptions are very important--indeed, that differences between their perceptions and ours would be particularly important. We conclude, however, that they have done little original work on the subject and show no evidence of regarding the whole matter as anything more than an opportunity for propaganda.

Deterrence: The evolution of U.S. strategic doctrine from the late-1940s to date is well documented. Throughout the past four decades, our policy has had to convince the Soviet leadership of the futility of aggression by ensuring that we possessed a deterrent which was sufficiently credible and capable to respond to any potential attack. Two years ago next month, the President's Commission on Strategic Forces (Scowcroft report) confirmed anew that effective deterrence requires:

- Holding at risk those military, political and economic assets which the Soviet leadership have given every indications by their actions they value most and which constitute their tools of power and control;

- Creating a stable strategic balance by eliminating unilateral Soviet advantages and evolving to increasingly survivable deterrent forces; and

- Maintaining a modern, effective strategic Triad by strengthening each of its legs and emphasizing secure and survivable command, control and communications.

These three principles are reflected in our strategic modernization program discussed below. Consistent with meeting our essential targeting requirements which derive from these three overarching deterrence principles, we also observe other policy considerations, three of which warrant special mention because they may serve to reduce concerns about climatic effects. They are a reduction of the number of weapons and total yield, rejection of targeting urban population as a way of achieving deterrence, and escalation control. Reducing unwanted damage must be an important feature of our policy, not only because of a categorical desire to limit damage that is not necessary, but also because it adds to the credibility of our response if attacked and thus strengthens deterrence. Over the past 20 years or so, this policy and other considerations have resulted in development of systems which are more discriminating. This, in turn, has led to reductions of some 30% of the total number of weapons and nearly a factor of four reduction in the total yield of our stockpile. This direction continues today, and the prospects for extremely accurate and highly effective non-nuclear systems are encouraging.

Some analyses of climatic effects of nuclear war have assumed targeting of cities. If this were regarded as an inevitable result of nuclear attack, or as U.S. policy, it would completely distort analysis of climatic effects, but more importantly, it would perpetuate a basic misperception of the nature of deterrence. Attacks designed to strike population would, by virtue of deliberately targeting heavily built up urban centers, necessarily have a high probability of starting major fires, and consequently, of creating large amounts of smoke. We believe that threatening civilian populations is neither a prudent nor a moral means of achieving deterrence, nor in light of Soviet views, is it effective. But our strategy consciously does not target population and, in fact, has provisions for reducing civilian casualties. As part of our modernization program, we are retiring older deterrent systems (e.g., the Titan missile) which might create a greater risk of climatic effect than their replacement.

A third element of our implementation of deterrence policy which bears on a mitigation of possible climatic effects is escalation control. It is our position that, however an adversary chooses to initiate nuclear conflict, we must have forces and a targeting capability so that our response would deny either motive or advantage to the aggressor in further escalating the conflict. (Of course, the prospect of our having such a capability would help deter the attack in the first place.) This objective has already in past years resulted in development of a wide range of combinations of targeting and systems selection options. While designed to strengthen deterrence and control escalation if deterrence were to fail, these options may allow us to adjust our planning so as to reduce the danger of climatic effects as our understanding of them develops.

There are those who argue, in effect, that we no longer need to maintain deterrence as assiduously as we have, because the posited prospect of catastrophic climatic effects would themselves deter Soviet leadership from attack. We strongly disagree, and believe that we cannot lower our standards for deterrence because of any such hope. As summarized above, there is large uncertainty as to the extent of those effects; certainly today we cannot be confident that the Soviets would expect such effects to occur as a result of all possible Soviet attacks that we may need to deter. This entire area of consideration--the impact of possible climatic effects on the deterrence--is made more complex by the fact that it relates to what the Soviets understand about such climatic effects and how that understanding would influence their behavior in a crisis situation. We will probably never have certainty of either; indeed, we cannot know the latter before the event, and knowing the former is made difficult by their behavior so far, which has been to mirror back to us our own technical analysis and to exploit the matter for propaganda. (Soviet handling of the "nuclear winter" issue is discussed more fully later in this report.)

The United States has, or is now taking, specific actions which relate directly to maintaining and strengthening deterrence and reducing the dangers of nuclear war: the President's Strategic Modernization Program, arms reductions initiatives, and the Strategic Defense Initiative all bear directly on effective deterrence, and are all therefore relevant to the potential destructiveness of nuclear war including possible climatic effects. We will now discuss these in turn.

Strategic Modernization Program: The President's Strategic Modernization Program is designed to maintain effective deterrence, and by doing so, is also an important measure in minimizing the risks of atmospheric or climatic effects. It is providing significantly enhanced command, control, communications and intelligence (C^3I) capabilities which, through their increased survivability and effectiveness contribute immeasurably to our ability to control escalation. Survivable C^3I contributes to escalation control and thus, as explained above, to mitigation of damage levels (of whatever kind, including possible climatic effects) by reducing pressures for immediate or expanded use of nuclear weapons out of fear that capability for future release would be lost. The improvements to our sea-based, bomber and (with the Scowcroft modifications) land-based legs of our Triad--all intended also to improve survivability and effectiveness--are also essential to maintaining deterrence.

For nonstrategic weapons, our modernization programs have also resulted in increased discrimination through improved accuracy and reduced yield. Beyond that, we have a good beginning on a program to replace some types of nuclear weapons by highly effective, advanced conventional munitions. All of this would contribute to reduction in possible climatic and other global effects of nuclear war. The possibility of such effects, of course, adds urgency to the implementation of these programs.

Arms Reductions: It is the position of this Administration that the level of nuclear weapons which exists today is unacceptably high. As a result, to the extent it is possible to reduce nuclear weapons unilaterally--particularly where both conventional and nuclear modernization programs allow replacement of existing systems on a less than one-for-one basis--we have undertaken to do so. But it would be misleading to suggest that dramatic reductions in nuclear weapons can be achieved by unilateral U.S. initiatives without increasing the risk of nuclear attack, in the absence of any indication that the Soviet Union is undertaking similar steps, or short of a changed strategic situation resulting from highly effective strategic defenses.

Major reductions in nuclear weapons can only be achieved by negotiating mutual and verifiable reduction agreements. Agreements which only legitimate the growth, or slow the rate of increase, of existing stockpiles are not in our national interest. It is for this reason that the Administration has determined that SALT II is fatally flawed. Since 1981, the Reagan Administration has demonstrated its strong desire to break with the past pattern of calling build-ups "arms control". The arms reduction proposals we have put forward have been the most extensive ones advanced by either side for over 20 years. In the area of Intermediate Range Nuclear Forces (INF), we initially proposed the elimination of all longer-range INF (LRINF) missiles--SS-20s, SS-4s, Pershing IIs, and ground-launched cruise missiles. While this remains our goal, we are prepared, as an intermediate step, to reach agreement on the reduction of U.S. and Soviet LRINF missiles. With regard to strategic weapons, we proposed reducing the number of each side's land-based and sea-based ballistic missile warheads to 5,000--a cut of approximately 33%. We have also called for equal limitations on bomber forces and restrictions on missile throw weight. As we prepare to resume negotiations with the Soviet Union in Geneva, we reaffirm our intention to seek agreements in both areas providing for significant, mutual and verifiable reductions.

As to how nuclear arms reductions bear on nuclear-induced climatic changes, the relationship is two-fold: they can strengthen deterrence--the most direct way available to us today of dealing with the possibility of severe climatic effects--and they can mitigate the effects to some extent if deterrence were to fail. However, nuclear arms reductions which may be achievable in the near term are not likely to be able to reduce significantly the consequences of a nuclear war in which a large proportion of the then existing nuclear forces would be used and in which active defenses would be non-existent or ineffective.

It is worth noting in this context, that proposals which would "freeze" development of modernized systems would also stop what has been a continuing trend in our capability--development of systems which are more discriminating and thus more restrictive in both local and global effects. We must avoid constraints that would force us to use weapons of high yield or unconfined effects.

The Strategic Defense Initiative and Arms Control: It is essential to keep potential benefits of arms reductions clearly in view when assessing what one seeks to accomplish through that process. Our objectives in arms reductions are to preserve deterrence in the near-term and begin a transition to a more stable world, with greatly reduced levels of nuclear arms and an enhanced ability to deter war based upon the increasing contribution of non-nuclear defenses against offensive nuclear arms. This period of transition could lead to the eventual elimination of all nuclear arms, both offensive and defensive. A world free of nuclear arms is an ultimate objective to which we, the Soviet Union, and all other nations can agree. The Strategic Defense Initiative research program enhances our efforts to seek verifiable reductions in offensive weapons through arms control negotiations. Such defenses would destroy nuclear weapons before they could reach their targets, thereby multiplying the gains made through negotiated reductions. Indeed, even a single-layer defense may provide a greater mitigating effect on atmospheric consequences than could result from any level of reductions likely to be accepted by the USSR in the near term.

In addition to its design objective to destroy nuclear weapons in flight, the Strategic Defense Initiative would further serve to remove any potential for environmental disaster by moving away from the concept of deterring nuclear war by threat of retaliation and, instead, moving towards deterrence by denial of an attackers political and military objective. Defenses can provide such a deterrent in two ways. First, by destroying a large percentage of Soviet ballistic missile warheads, an effective defense for the U.S. and our Allies can undermine the confidence of Soviet military planners in their ability to predict the outcome of an attack on our military forces. No rational aggressor is likely to contemplate initiating a nuclear war, even in crisis circumstances, while lacking confidence in his ability to predict success.

Second, by reducing or eliminating the utility of Soviet shorter-range ballistic missiles which threaten all of NATO Europe, defenses can have a significant impact on deterring Soviet aggression against our Allies. Soviet SS-20s and shorter-range ballistic missiles provide overlapping capabilities to target all of Europe. This capability is combined with a Soviet doctrine which stresses the use of conventionally-armed ballistic missiles to initiate rapid and wide-ranging attacks on crucial NATO military assets. By reducing or eliminating the military effectiveness of such ballistic missiles, defense systems have the potential for enhancing deterrence not only against intercontinental nuclear attack, but against nuclear and conventional attacks in Europe as well.

Some critics claim that the SDI program would cause the Soviet Union to increase numbers of weapons in an attempt to overcome the defense. This is related to the argument advanced over a decade ago that, by rendering ourselves totally vulnerable to Soviet weapons we would be able to negotiate limits on those weapons. This logic has, of course, been disproven by events; despite the fact that the U.S. made itself fully vulnerable, the U.S.S.R. increased the number of its weapons fourfold since the signing of the ABM Treaty in 1972. The guarantee that all Soviet weapons would reach their U.S. targets apparently did not give the Soviets an incentive to negotiate an equitable SALT II agreement, it encouraged them to build more weapons. Defenses would have the opposite effect; they would reduce the military and political value of ballistic missiles thereby increasing the likelihood of negotiated reductions. The prospect that powerful emerging technologies will reverse the cost leverage which offensive forces have heretofore had over defenses will further improve the likelihood of negotiated reductions.

Thus, by preventing the detonation of thousands of nuclear warheads, and, by paving the way for the elimination of those warheads by making them obsolete, the Strategic Defense Initiative may provide an answer to both the short-term and potential longer-term consequences of nuclear war.

Civil Defense: The basic goal of civil defense in the United States is to develop and maintain a humanitarian program to save lives in the event of major emergency, including a nuclear war. As to changes in our Civil Defense posture, the Federal Emergency Management Agency believe that until scientific knowledge regarding climatic impacts of nuclear conflicts is more fully developed it would be impractical to develop cost-effective policies regarding civil defense, or to change existing policies.

The particular staff elements within the Federal Emergency Management Agency responsible for civil defense planning are being kept abreast of the issues relative to possible climate effects as they develop and will be prepared to take appropriate action as soon as the relevant research now underway is complete.

As we have shown, much of our long standing policy and our current initiatives move in a direction such as to reduce the probability of severe climatic effects even though they were instituted before such effects were under investigation. Specifically, we are maintaining a strong deterrence augmented by necessary force modernization and verifiable, mutual arms reductions. We are continuing the development of accurate, discriminating systems designed to achieve their military objectives with the least nuclear yield possible. We have implemented and are constantly refining options for escalation control. We have, long ago, rejected the targeting of population as a means of securing deterrence. Finally, we have begun the Strategic Defense Initiative which has as its ultimate goal the obsolescence of nuclear weapons. All these things work first to deter nuclear war--the best way of avoiding the effects at issue--and second, to reduce these effects were deterrence to fail.

Possible Further Initiatives: As we have already pointed out, reducing unwanted damage must be an important feature of our policy. It would be entirely consistent with our policy and recent practices to continue to make weapons more discriminating, to reduce their yields by improved accuracy where possible, and in other ways to minimize effects not directly related to target damage, so as to both enhance the credibility of our deterrent and to reduce unwanted destruction, including the potential for ameliorating possible climatic and other environmental effects. In fact, we are pursuing such objectives in general, though programs are in various stages of development.

Beyond these continuing trends, with regard to targeting and the detailed characteristics of the nuclear forces, which pertain both to deterrence and to limiting damage, as our understanding of climate effects improves it is prudent to develop other measures intended to reduce those effects if deterrence were to fail. Besides possibly adding targeting options to those which already exist to limit damage, some technical developments might also contribute. For example, highly accurate, maneuverable reentry vehicles and earth penetrating weapons, both of which might be useful in strengthening deterrence, could reduce yields and in other ways limit the starting of fires. In the farther future, for selected missions, nonnuclear systems, if feasible, might replace some strategic nuclear systems, as we have begun to do for non-strategic systems.

Today, however, we have inadequate knowledge to evaluate possible measures. As the analytical methods for assessing climatic effects become more accurate and we gain confidence, they can be used to predict what kind of changes will in fact reduce the dangers of nuclear war. For example, some have suggested that reducing the height of burst of the nuclear explosions could reduce the area of thermal effect and, therefore, the amount of material burnt. However, at lower heights of burst, increased fallout might be worse than any mitigation of long-term change in the climate. Where such trade-offs are involved, we need better information before deciding.

4. Soviet Activities on Climatic Effects

Soviet science spokesmen and media have claimed that Soviet scientists had independently confirmed the probability of severe long-term atmospheric effects as a consequence of nuclear exchange. Initially, their claim was accepted in the West; however, an examination of open Soviet publications specifically discussing this prediction shows their claim to be unfounded.

In their writings on the "nuclear winter" hypothesis, Soviet scientists have neither used independent scenarios nor provided independent values of the essential parameters characterizing the key ingredients (soot, ash, and dust) on which the hypothesis principally depends. Instead, Soviet researchers--and on this subject, it is hard to tell the difference between scientific workers and propagandists--have uncritically used only the worst-case scenarios and estimates from other work. They have taken these estimates and merely adapted them to borrowed mathematical simulations of state-of-the-art multi-dimensional models of global atmospheric circulation modified to instantaneously simulate long-term global effects after an exchange. For example, the primary atmospheric circulation model used by the Soviets in the case of the widely publicized study by Soviet researchers V. Aleksandrov and G. Stenchikov, is based on a borrowed, obsolete, U.S. model. Thus, given the sources of inputs and methods for their "studies," their findings do not represent independent verifications of the hypothesis.

Further, Soviet reports tend to stretch the conclusions well beyond what even their uncritical, worst-case assessments support, embellishing statements of technical analyses with conclusions that any use of nuclear weapons at all will lead to the disappearance of the human race or similar propagandistic statements the Soviet Union has made on and off for years, even before these atmospheric phenomena surfaced.

The Soviet scientists have contributed very little to the international study or understanding of this phenomenon. This shortfall has not gone unnoticed by other non-Soviet scientists, some of whom have characterized their analyses as "crude" and "flawed." Time after time their presentations contain exaggerated claims, which are criticized by their foreign colleagues following the formal briefing, but subsequent presentations do not reflect any change, even though in private the Soviets acknowledge the exaggeration.

This is not to say that, over the years, the Soviets have not published studies that have examined various effects and phenomena (dust, fires, soot, etc.) of nuclear detonations; they have. However, the Soviets have made little use of such findings in their public discussions and models of the phenomenology associated with the current climate effects hypothesis. They have not been forthcoming in providing information that might have been of use with regard to reducing the uncertainties associated with the assumptions made in their work. Repeatedly, they ignored an American request for information derived from Soviet pre-1963 nuclear tests and large-scale fires. The flow of useful technical work has been almost all one-way. It is worth noting that Soviet interest in this topic provides them with some degree of additional access to U.S. scientists (and their technology) who are involved with super-computers, software model development, and global and mesoscale climate phenomenology.

If the Soviets see this issue as a matter that might substantially affect their policies, strategy, or force structure, those views have so far been hidden from us. It is important that, whatever the outcome of the scientific work regarding climatic effects of nuclear war, the understanding should be commonly held by all of the nuclear powers and help to reduce the risk of nuclear destruction. Unfortunately, recent Soviet performance and statements on the subject do not appear supportive of establishing a truly common understanding, either on the phenomena themselves or on their implications for the strategic relationship between the two powers. If the Soviet leadership does believe that the possibility of severe climatic effects is important, then this issue will add its weight, along with the many other imperatives which the United States and the people of the world feel so strongly, to produce a truly constructive approach toward a world in which the fears aroused by such horrors as nuclear war or the so-called "nuclear winter" will be a thing of the past.

Chairman **Goldwater**. Senator Nunn, do you have any questions?

Senator **Nunn**. Mr. Chairman, I missed the first couple of witnesses and will try to catch up.

I will defer to colleagues who were here before me.

Chairman **Goldwater**. Senator Cohen?

Senator **Cohen**. Mr. Gillespie, what are the temperature drops that you assume, what range are you talking about in terms of assuming so-called path of exchange?

What is the range of temperature drop?

Dr. **Gillespie**. That is a hard question to answer with just one number.

Senator **Cohen**. What baseline are you operating from?

Dr. **Gillespie**. It varies in time and it varies depending on where you are.

Let me try to give a few numbers that perhaps will help a little bit. If you are deep in a continental interior, the bottom of the temperature drop—now, these are the baseline assumptions in the various cases that I have talked about—then I think you could expect in the summertime to see the temperature drop by perhaps 50°F.

That is sort of a nominal number. In more coastal regions the temperature drop would be very much less than that. I am not comfortable with giving a number there because our models so far cannot really treat this rather unique coastal region.

Actually, it is a fairly broad band around the coast or inland from the coast. The thing we are sure of is that the temperature drops would be very much less there.

Senator **Cohen**. You indicated in one of your conclusions that one of the immediate consequences would be that there would be no food for that year, assuming the baseline exchange, either I assume in the summertime, spring or winter.

Dr. **Gillespie**. Whether or not a wintertime exchange would result in the destruction of the following year's crop would depend on how long the effects last.

I think in the baseline case it is certainly not at all outside the bounds of reasonable speculation that effects from a winter exchange would last well into the following summer and that you very well could lose much production the following summer.

Senator **Cohen**. Also I think some of your studies are predicated on the fact that we were going to be targeting silos rather than cities.

Mr. Sloss, you indicated that nonetheless we would be targeting some cities because some military sites are located in cities.

An item in yesterday's paper talked about an ABM site around Moscow. Obviously, if you are talking about a nuclear exchange, one of the first targets would be to take out an ABM site in Moscow itself. So, there is a major city that would be targeted.

I assume Washington, DC, would be targeted and many of the major industrial areas that have naval facilities, not to be specific, San Diego, Seattle—perhaps Bath Iron Works in Maine, to be equitable.

I assume when we start talking about just military targets, it involved a good many urban areas, nonetheless.

I was wondering if we have diminished the significance of the analysis by saying we are really focusing on military silos.

One question which has been discussed recently by the Academy of Sciences is the impact of fire, wild fires in the rural areas. What about the impact in terms of destructive capability of fire storms as such? What sort of analysis has been done on that?

Dr. GILLESPIE. The baseline model derives most of its smoke input from burning cities. In particular, it comes from plastics and the hydrocarbons, fuel, things of that sort that are associated with cities.

In fact, the key part of the nuclear winter hypothesis is the burning of cities.

Senator COHEN. The study you did, I think, mentioned that you tended to concentrate on the fires that would have occurred, I think, in nonurban areas.

Dr. GILLESPIE. Let me try to clarify that a little bit.

In trying to attack various individual pieces of the whole nuclear winter problem, one of the things that we attacked first was just the question of fires having to do with nonurban targets just as a piece of the problem, in no sense intended to represent a unique attack or anything like that.

We just looked at that piece of the problem because it was easier; it was a learning experience for us; we knew we could get results or we felt we could get results there faster. Indeed, that turned out to be the case.

So, in that one particular class or subset of targets, what we showed was that the amount of smoke produced was much less than some of the initial estimates. As I said, that doesn't change the concern for the smoke in cities.

Senator COHEN. Dr. Harwell, you indicated in your testimony that in the previous studies many uncertainties have been resolved.

What are the uncertainties that have been resolved, in your judgment?

Dr. HARWELL. Dr. Gillespie has mentioned the issue of temperature decreases over the continental area versus ocean areas. There have been more studies that have been done in the last 6 to 9 months that have tried to refine the differences there, what sorts of consequences that would be.

As another example, I think probably the most important issue that was brought out in the beginning of the nuclear winter idea was how high up smoke would go and what its duration would be.

In the last 6 to 9 months, some very sophisticated, three-dimensional models using Cray computers at Livermore and Los Alamos and other places have tried to deal with that issue, specifically including the interaction of the solar heating of the smoke, causing the smoke to rise buoyantly like a hot air balloon. A number of different, independent models have shown it really didn't matter how high the smoke went initially, that it would wind up in very, very high altitudes if it was a war during the spring or summertime.

Further, once it reaches high altitudes, which would be in the stratosphere, there would be quite a bit of transport across the equator into the Southern Hemisphere, another issue that was clarified by these studies.

Senator COHEN. Dr. Gillespie indicated that the studies done on baseline could be off by a total factor of 10, one way or the other.

Dr. GILLESPIE. I used that as sort of a minimum bound. I think it is very hard to put a specific number on it. The point is that it is a very large range of uncertainty.

Senator COHEN. Assuming that to be the case, assuming that baseline that was used to study was off by a factor of 10 and assuming that it is not as severe, what would be your conclusion—even assuming that we are better off by a factor of 10 in terms of that analysis, what would be the consequences assuming that to be true?

Dr. HARWELL. With respect to the climatic effects alone, the range of values associated with the best estimate, not the worst side or the minimum side, but sort of a median estimate, is in the range of 20 to 40 degrees Centigrade decreases in temperature during the acute time period.

If you reduce those by a factor of 10, you would still be in the range of 2 to 6 degrees Centigrade, which is 5 to 10 or so degrees Fahrenheit. Temperatures in that range are more than adequate to disrupt the production of virtually any grain crop in the Northern Hemisphere. Thus, even if you could reduce the temperature decrements by a factor of 10, you still would have very consequential problems.

Another point is that the response that Dr. Gillespie mentioned earlier is nonlinear. If you dump a lot more smoke in the atmosphere, the temperature decreases don't get a lot larger.

On the other hand, the atmospheric effect becomes saturated with particles at considerably less a level than is in the baseline scenario, so a much smaller scenario could still lead to very significant temperature decreases.

A 10-fold reduction in particulates would not necessarily result in a 10-fold reduction in the amount of temperature decrease. The range of uncertainties for most of the estimates that come out of the climatic side are above the threshold of causing agricultural effects.

As a separate issue, if there were no climatic effects whatsoever, clearly in a number of different ways, the indirect effects on agricultural production and food distribution would still be very consequential.

Senator COHEN. Mr. Sloss, you indicated that you don't think there is any realistic possibility that there will be an all-out exchange, that both nations have it in their interest not to let the nuclear exchange go out of control.

What is the basis of your statement?

Mr. SLOSS. I certainly didn't mean to say that there was no possibility. What I did want to convey was that the possibility for limited exchanges and insofar as a study of this issue of nuclear winter, it seemed to me more realistic to focus on those.

I certainly did not mean to imply that an all-out exchange was impossible.

I wanted to try to comment on what is a very common attitude among some commentators that any nuclear exchange must inevitably be all out. I don't agree with that.

To repeat, it seems to me that if we are concerned about nuclear winter, the more relevant case is a study of more limited cases. This phenomenon then becomes important in relation to the direct effect.

Senator COHEN. You stated that if there is in fact an all-out exchange, we should not worry about the impact or the theory of nuclear winter.

What do you mean by that?

Mr. SLOSS. I think the direct effect of that exchange will overwhelm the nuclear winter. With 40 or 50 million direct casualties, we are not going to be worried so much about our food supply.

Senator COHEN. I think it makes a difference if there are 40 to 50 million casualties compared to 4 billion casualties. If you have a problem where you have 40 or 50 million casualties, that differs from when you face the possibility that the human species cannot survive.

I think, Dr. Gillespie, you indicated there was no scientific hypothesis or conclusion that there would be an eradication of the human species.

Dr. GILLESPIE. I would rather characterize that as my personal opinion based on having been involved in this for the last 2 years.

I think the initial assertion that it was a distinct possibility was not based upon any very careful or thoughtful assessment. Those were statements that were made very early on in the debate and I think, looking at the result now, I just see no reason to make such a statement.

Senator COHEN [presiding]. Senator Levin?

Senator LEVIN. Thank you, Mr. Chairman.

First, I want to ask Dr. Gillespie some questions about the policy implications which I understand you have not assessed.

Dr. GILLESPIE. No, sir.

Senator LEVIN. Your testimony is that that is not your bailiwick to test those implications.

Dr. GILLESPIE. That is correct.

Senator LEVIN. Where in the Department of Defense are those implications being studied?

Dr. GILLESPIE. I think that is a matter for Mr. Perle to talk about. I understand he is talking tomorrow. It would be presumably in his shop, or such as that.

Senator LEVIN. For purposes of our discussion, would you agree there are significant policy implications to this theory if in fact you are satisfied that it is accurate?

Dr. GILLESPIE. Yes, sir, I think there can be very far reaching policy implications, particularly as Mr. Sloss has outlined, having to do with the credibility of the deterrence.

Senator LEVIN. Could those implications, for instance, affect the priorities of our defense budget, what kind of weapons we buy?

Dr. GILLESPIE. I presume that they ultimately could. Again, I am getting out of my area of expertise.

Senator LEVIN. Assuming you are acting on the assumptions which you said you are under that there are significant policy implications, although that is not your department to determine what they are, then the question comes whether we are doing adequate research in a program which has, or might have significant policy implications.

I understand that the research budget is about $5 million.

Dr. **Gillespie**. Yes, sir, $5.5 million for this fiscal year.

Senator **Levin**. That was for 1985?

Dr. **Gillespie**. For 1986. It ran very close to that in 1985, however.

Senator **Levin**. How much money could we usefully spend on a research into a theory which would have such significant policy implications? What is our maximum useful expenditure?

Dr. **Gillespie**. In a scientific research program it is always possible to spend a lot more money. If we were to attack this on a crash basis, if you will, one could usefully spend several times the amount of the $5.5 million budget that we have now.

Senator **Levin**. What was the request to the Defense Department for this program for 1986? What was your request to DOD?

Dr. **Gillespie**. I made no specific broken out request, if you will, to DOD. In the interagency arena or interagency group it was agreed that there would be a total national budget of $5.5 million and DNA agreed to put in $2.5 million of that amount, but it is not specifically identified in our budget. It is not a specific line item.

Senator **Levin**. So, there was nobody inside this program that was pressing for greater funding than the $5.5 at any point in the budget cycle?

Dr. **Gillespie**. No, sir.

Senator **Levin**. I would like, Dr. Harwell, for you to comment on the Soviet contributions or lack thereof to the nuclear winter theory.

Is it your understanding we have gotten no independent contribution from the scientific community in the Soviet Union?

Dr. **Harwell**. The answer is different on the biological versus the atmospheric side.

On the atmospheric side there has been some contribution that has come from the Soviet scientists.

Senator **Levin**. Independent contribution?

Dr. **Harwell**. Independent in the sense of taking models that initially were United States developed, which is what the current Soviet models are, but 20 years out of date, but they have actually themselves gone about modifying the models to be able to do things like blow smoke around, and to deal with interaction in the atmosphere and oceans.

These were modifications to the climatic models that the Soviets have not done before and they did that in the context of doing nuclear winter calculations. There was some measure of that.

By and large, the Soviets did not do an independent assessment of the smoke production. They just analyzed, given that the smoke was there, how it would translate into climatic effects.

On the biological side it is quite a different picture from the atmospheric in that when we had a Scope workshop in Leningrad in May 1984, the Director of the Laboratory of Mathematical Ecology attended that workshop and in response to it initiated a very large research effort that resulted in a book published in English within the last few weeks, about the same size as our volume 1, running

300 or so pages, dealing with what the ecological consequences of nuclear winter would be.

This is done independently. The Soviet scientist came to the United States. We worked with him translating it into English, and it covered a lot of ground we did not get into in the Scope project. However, it did not get into the agricultural effects.

Senator **Levin**. Would you say, in your view, there has been some independent useful Soviet research?

Dr. **Harwell**. Certainly on the biological side there has been far more funded research than in the United States. That is not to say that we agree technically with the answers they came up with, but there has been a biological concerted effort within the Soviet Academy of Sciences Computing Center.

Senator **Levin**. Are you familiar with that last study that came out a few weeks ago?

Dr. **Goure**. No, sir, I have seen a summary of it, but it has not been distributed yet.

Senator **Warner**. Dr. Goure, to the extent that the Soviet nuclear winter study is largely motivated by propaganda uses, what is your assessment of the impact on the western world, particularly in Europe?

Dr. **Goure**. The effect of the nuclear winter propaganda?

Senator **Warner**. Yes.

Dr. **Goure**. On the Russians themselves?

Senator **Warner**. No, by the Russians on Western Europe.

Dr. **Goure**. It has not been as much a focus in Europe from that point of view than the United States because we have had greater activity here relating to discussions of nuclear winter. Nevertheless, the Soviets have been able to attend a whole series of conferences which were well covered by the European press on nuclear winter subjects in England, Germany, Holland, Italy, and so forth, and have been doing that for a number of years.

So, there have been essentially the same Soviet line and the same statements and interviews given out in Europe. They also did this at public conferences which were held in Europe with American participation. And, of course, the Soviet journals and articles which discuss these issues are translated and appear in German, Spanish, Italian, and so on. They are given considerable circulation.

As far as the European scientific community is concerned, the coverage has been as broad as it has been with the American scientific community and with the media pretty much the same, as well.

Senator **Warner**. Mr. Sloss, in your experience, is there a potential dramatic change in the formulation of the target policy?

Mr. **Sloss**. I would have to say not directly. My direct experience goes back 3 or 4 years now before this became a prominent issue. We have had considerable concern with collateral effects of varying types.

Some of the things we have done in targeting policy producing collateral effects would also produce nuclear winter effects. In the time I was heavily involved in this in the late seventies, this was not a primary issue.

Senator **Warner** [presiding]. Senator Glenn?

Senator **Glenn**. Thank you, Mr. Chairman.

I have followed this whole concept closely since we first talked about nuclear winter. We are truly in a new era. It is the first time in the history of mankind that war may directly affect every single person on Earth, not just combat participants.

I don't know what more modeling will do for us. I want to do it. I intuitively want to know more about this. I want to do research on it, but I am not sure what the purpose is.

I share Senator Levin's concern that we provide adequate funding. Obviously, we want to know what is going to happen.

Is our research supposed to show it will scare the Soviets out of contemplating attack or scare us out of defending ourselves with nuclear weapons if attack comes?

We know that nuclear war will be more hideous than anything that has ever happened. I am not quite sure what we are supposed to show out of this increased modeling even though I want to see it occur.

My interest in this goes back to Jim Van Allen, his study of the radiation belts. We were shooting rockets up and people were kidding about his experiments.

Then we found out there were radiation belts up there we didn't even know about. We found out at times of high solar activity that the flow of radiation out from the sun was actually flowing around the Earth like a bow wave and changing some of the heating of the upper atmosphere and that was changing some of our jet stream patterns.

I have always thought this nuclear winter, while we go into the overall changes in huge areas of the Earth from scattering absorption, and so on, I think the more likely danger is that our difficulty would come from the changing patterns of the jet stream because any of this debris or absorption will occur above the jet stream and make the United States into the desert and the Sahara into green vegetation.

I have always thought maybe these tiny changes we have observed from the Van Allen changes up there and the effect we would have from any nuclear blast in that area or nuclear debris in that area might be a far bigger effect than the overall absorption over a major portion of the Earth that we have talked about here this morning.

That is a rather general statement, but I would appreciate your comments on that.

No. 1, what do you want to do with the research money, in what direction would it go, what would be the purpose of it?

To scare us all out of war, I guess it is, hopefully, and do you see the minute changes, jet stream changes, as being a greater danger than the overall climatic changes we have talked about?

Dr. Gillespie, first, or whoever wants to.

Dr. GILLESPIE. I will rush in. You have asked several things there. So, prompt me if I don't get them right.

As to the possibility of perturbations of the jet stream, and so on, if the consequences are anything like the baseline predictions that I have talked about, then certainly there are major perturbations.

We are almost certain that that is the case of the jet stream, of the weather, of the normal circulation patterns in the atmosphere.

Although several people have looked for more long-term, very fundamental type changes, long-term, permanent changes to the climate, I have not seen anything that anyone has turned up there that looks particularly worrisome.

It does appear now that we do recover from the nuclear winter over a period of weeks or months or in some cases several years perhaps, depending upon how certain parameters go.

Senator **Glenn**. We are not without some information in this subject. Mount St. Helens blew up. We had a dust cloud around the Earth.

How much research did we do on that and how did that correlate with theoretical models that could relate with nuclear exchanges?

Dr. **Gillespie**. We can't give you a good answer to that. I think Mount St. Helens is not the best example of major events of that sort. Certainly the most dramatic one was Tambura which exploded in 1815, and produced the so-called year without a summer in 1816.

Unfortunately, we don't have good hard scientific evidence, but there seems to be pretty good reason to think that had a very significant impact upon northern hemisphere food production in the year of 1816.

So, models are able to predict some of the large-scale, long-term perturbations that have been produced. I think El Chicon in Mexico was properly modeled and El Nino has been modeled.

Senator **Glenn**. My time is up.

Senator **Warner**. Senator Wilson?

Senator **Wilson**. Thank you, Mr. Chairman.

Gentlemen, since we have limited time, I will let anyone who wishes to respond to this do so, but it seems clear from what we have heard that the hope that some of the advocates, the popularizers of nuclear winter have hoped for is the sobering effect on the leadership of the two superpowers.

Yet it seems equally clear that the sobering effect has not been achieved and the Soviets clearly do not seem to have been particularly affected by it, obviously, since there has been no discussion in the Soviet Union.

Nonetheless, studies have been published in Russian.

Has there been any genuine contact?

I am concerned that Aleksandrov once he began to apparently appreciate his own efforts, mysteriously disappeared.

Is the purpose of this to really sober and dissuade people from engaging in the kind of attacks that might produce nuclear winter?

What real contact has been made with the Soviet scientific community?

Obviously, the Soviet military is having none of it.

Let us begin with Dr. Harwell.

Dr. **Harwell**. I want to comment on one of the points, the issue that the Soviet studies have not been translated into Russian. That is not correct.

The atmospheric and biological studies have been translated into Russian. A Soviet journal, the title is the equivalent of "Nature," had a special issue on the consequences of nuclear war, all in Russian, with English abstracts, that fully reported on the studies done by the Soviet Academy of Sciences on both the climatic calculations and biological and ecological calculations.

In the scientific community there has been fairly broad dissemination. In my contacts with scientists in the Soviet Union there has been reported quite a bit of discussion in the scientific community.

Dr. GOURE. There has been a lot of contact. Of course, the nuclear winter interest has broadened the contact. The Soviet scientists come here. Some of them, Aleksandrov, for example, spent some time in the United States, at Livermore and other institutions.

Our scientists have visited the Soviet Union and have attended various symposiums or conferences in Russia.

The question is really what has been the result of this? I repeat, Soviet scientists are not free to travel and to discuss. That includes those who visit the United States.

Certain things have been published, but the whole thing is controlled. Aleksandrov's technical study was never published in the Russian language.

As of now, the Soviets, when they write about this subject, write publications which appear in English. There is no Russian version of it. So, it has served their propaganda purposes.

The fact that we have a personal relationship between scientists, and sometimes very warm ones, doesn't change the issue of how the effort is orchestrated on their side as against here. Most of the people who started the nuclear winter debate in this country have done it outside of Government studies. They were not Government-sponsored activities. In some sense they argued against current Government views. In the Soviet Union there is no such thing as nongovernmental research, nongovernmentally approved writings, nongovernmentally approved speeches. If you try, you may finish up like Aleksandrov, you disappear.

Senator WILSON. I should like to ask Dr. Gillespie to comment for the record at whatever length he cares to on the criticisms that have been made by Freeman Dyson of Princeton and Professor Wysok at MIT who have greatly depreciated the science of the nuclear winter.

I think a quote from Dyson is that the physics was atrocious and Wysok said the psychology might be useful; for science, it is terrible.

If you can give us in writing some response. Perhaps we should ask them for a response, but since you are a focal point of that particular inquiry, I think it would be useful.

Dr. GILLESPIE. Yes, sir.

[The information follows:]

NUCLEAR WINTER AND ITS IMPLICATIONS

We are not acquainted with the background or circumstances surrounding such comments by either of these distinguished scientists. Given the associated assumptions and uncertainties, we believe the scientific work underway on the nuclear winter hypothesis is sound. Our global effects research program involves a fairly large number of prominent scientists in the fields of interest, representing the national laboratories, the academic community, and industry. These nationally and internationally known experts are participating in the program as researchers and advisors. Consequently, the program is focused on the principal assumptions and uncertainties recognized by these experts.

Senator **Warner**. Senator Exon.

Senator **Exon**. Thank you, Mr. Chairman.

Gentlemen, thank you for coming here. This is an important matter.

I have attended several conferences on this subject. I believe that the real understanding of this is beginning to seep into the American public, not only by the fact that there has been considerable, and I salute that, emphasis from the scientific community about the effects of a nuclear winter and exchange between the Soviet Union and the United States of nuclear devices.

I want to know what you think the purpose of all of this is with regard to people in the United States. Certainly I also commend many of the documentary series that I have seen on television and elsewhere that I applaud.

Some people didn't like that because they thought the people may take that as a meaning that we have to stamp out all of our nuclear weapons and we would be defenseless, which was not how I took it.

The intent of those programs was rather to inform the public as to what we are up against.

My first question has to do with the continued emphasis in the Soviet Union on civil defense activities. I am wondering how broad you think the devastation of a nuclear winter is generally understood by the Soviet people?

I suppose you might be the expert on that, Dr. Goure.

And, also, my second question, a follow up to that, is: Has there been international scientific meetings inside the Soviet Union and, if so, how much publicity have those scientific meetings with regard to nuclear winter had?

Has it received any publicity by the Soviet-controlled press?

Dr. **Goure**. Senator, on the latter question there have been quite a few conferences. Coverage has varied a good deal. In general terms, the Soviet media has usually summarized statements by Soviet scientists, but had little to say about those of foreign scientists.

Occasionally you have had TV interviews with some of the participants including foreigners. I have surveyed a large amount of what the media told the public in Russia about nuclear winter. I find this is generally vague. It generally says that there could be darkness and freezing, it does not go into any of the details we tend to discuss and publicize here.

The agricultural issues usually are not discussed in those terms at all, at least publicly. I don't mean it doesn't arise. However, it does not arise in the civil defense materials, that is not in terms of the nuclear winter, but simply in terms of the effect of fallout.

From that point of view, the Soviets accept the notion that the standing crops at the time of attack would probably be destroyed or severely damaged by fallout as well as by fire and you would essentially lose pretty much all the crops growing at the time of the attack.

The idea from their point of view is how one reconstitutes it afterwards, the next growing season or later, and how one survives in the meantime on food stocks and organizes their distribution.

Concerning Soviet attitudes toward civil defense, I would say that a certain amount of information about the magnitude of a nuclear disaster has penetrated and been reflected in the Soviet press. On the whole, the Soviets do report that some people say in Russia: What is the good of studying civil defense, if there is a war we all die.

But the instructors and official position take the line that these people are wrong, that one must make them understand that if you do the right thing, it will be OK. The objective, stated public objective, of Soviet civil defense propaganda instruction is said to instill in the public confidence in the effectiveness of civil defense measures. Whether they always succeed is something else, but at least that is the objective. Officially this is what they pursue.

Senator Exon. So, it would be fair to say you are convinced that the Soviet citizen generally probably does not have the understanding of the destruction by a nuclear exchange to the extent that western people who live in western nations are; is that correct?

Dr. Goure. Probably not. However, they are afraid of war to a considerable degree, given their World War II experience, but not necessarily to the same extent in terms of those details of weapons effects. There is no antinuclear movement in Russia the way there is one in the United States or in the West.

Senator Exon. I think that the mind set on surviving what we did in World War II is one of the real dangers that we have and we have to overcome. As we all know, it is a totally different situation.

One last question and I will ask each of you. One of you, however, might want to respond to it.

Getting away from the horrors of the nuclear winter that we have been focusing on, fallout and what it would do to our weather pattern, looking ahead 20 or 30 years, if we are able to survive the threat that is posed today, and let us say that given the present technology that we are attempting to develop to where, you know, theoretically at least, no nuclear device fired at others from anywhere would ever get through, it would be destroyed in the atmosphere someplace, I am not sure that I understand what your view is on that, if you have one, with regard to what it would do to the atmosphere of the world if all of those nuclear devices were destroyed up there someplace and none of them ever landed.

Dr. Gillespie. I feel fairly comfortable in saying that if you can destroy those nuclear devices somewhere else other than within the atmosphere, we will be a lot better off from the nuclear winter point of view, or any other.

I am not concerned that destruction of these devices above the atmosphere is going to have some peculiar unforeseen occurence.

Senator Exon. What you are saying is that would be a significant step in the right direction if the ultimate goal of SDI is totally successful?

Dr. Gillespie. Yes, sir.

Senator Exon. Do you all agree on that?

Mr. Sloss. I don't pretend to be an expert on what would happen in the upper atmosphere. I certainly agree if we can keep nuclear weapons out of the atmosphere, we would certainly be a lot better off.

I am not confident that there would be no effect, but we would be better off. I have some skepticism about our ability to do that.

Dr. **Goure**. Obviously, any defensive system that will reduce the threat on the ground and in the atmosphere; that is, the number of weapons that would detonate there, would be a tremendous step in terms of limiting damage, whether it is from nuclear winter or from fallout, or what have you.

In fact, even if it is imperfect, there is a big difference being on the receiving end of 6,000 or 10,000 warheads or of a few warheads. Irrespectively, they certainly will have a bad effect but a lower number will not be as devastating as a larger number.

Dr. **Harwell**. We have not dealt with policy issues in this Scope study, whatsoever, so we did not get into things like the efficacy of star wars and the context of indirect effect, but some aspects that we did look at bear on this question and that relates to the key issue in terms of causing climatic effects is production of smoke.

Our smoke calculations were not tied to 5,000 or 6,000 megatons of weapons necessarily detonating in one country or another, but we looked at how much smoke would be produced by fire in urban areas in particular.

Something on the order of less than 100 urban areas set on fire would be more than enough to cause the very significant climatic effect associated with nuclear winter. Fewer fires could lead to lesser effects, but still climatic consequences.

So, the key is that you would have to have almost complete interference with any detonations that could lead to urban fires, both in the Western and in the Eastern hemispheres. So, with respect to smoke production, you would have to have almost a perfect shield to preclude that.

The other issue, even without fires, is the other types of indirect effects that would follow from a large-scale nuclear war for which there were no climatic disturbances and those indirect effects are extremely consequential, even more than direct effects.

Cutting out the climatic effects would not get you out of the global consequences we have been discussing.

Senator **Exon**. Thank you, gentlemen.

I will say in answer to your statement, Dr. Harwell, that looking at it a little bit, which we have to do from time to time, it will affect the next generation for a long time to come.

If I understand the general strain of what you are saying, either you don't know—we have not done any research—but your offhand opinion would be that we probably would not have any significant effect if we did conduct a war in space, if that is where the destruction took place, and that likely would not have any effect on the Sun's rays.

In other words, it would be full of debris in space, but not have a significant effect on human life here.

Is that a fair assumption to make from what I have heard you say?

Dr. **Harwell**. If you had detonations strictly occurring in the upper atmosphere or in space, you would not generate the sources of smoke that would lead to the climatic effects.

Senator **Exon**. I understand that. That is very evident.

Dr. HARWELL. It is not clear what the effects of multiple detonations in space or in the upper atmosphere would be. There is potential for things like disruption in the ozone layer if instead of being totally in space, it is in the upper atmosphere.

There are a lot of other mechanisms by which the indirect effects of a large-scale nuclear war, even without climatic consequences, would still be very catastrophic.

Senator EXON. And we don't know much about it?

Dr. HARWELL. We don't know much about it.

Senator EXON. Thank you.

Thank you, Mr. Chairman.

Senator QUAYLE. I would like to ask Mr. Sloss this question.

If we were to assume the nuclear winter theory, what kind of course, particularly in selecting our weapons systems, do you think we ought to be pursuing?

In what direction should some of our weapons systems be going to counter this problem?

Mr. SLOSS. I think the first thing that it does is to reinforce something we have understood for a long time and that is the point of deterring nuclear war.

Second, though, I think the importance, in my view, is importance of limiting the effects of the weapons that are used. It seems to me it reinforces the need to do that.

In terms of weapons, I think we want to continue to reduce yield of nuclear weapons if we can do it and improve the accuracy of weapons.

I suggest in my statement that one type of weapon that has been dismissed largely by the nuclear planners up to now may look more interesting because of the nuclear winter effects, and that is the earth-penetrating weapon, which can achieve significant damage in a ground shot without any atmospheric effects.

I think that we need to look at that weapon and some others which would enable us to inflict damage on targets without creating the atmospheric effects.

I also suggested we look at our plans. I think defense can play a role. Obviously, the more weapons we could shoot down will also contribute to deterrence which ought to be our first objective.

Finally, I think that arms control can play a role in this, too, although I believe that is a longer-term process and we cannot rely on that. We need to have some alternatives.

That is why we ought to be looking particularly at weapons and plans to be sure that what we have minimizes the potential consequences of that effect.

Senator QUAYLE. Does anyone want to add to that?

Dr. GOURE. There are some other things that need to be investigated and that is the question of targeting: how you go about it, the relationship of weapon yield, accuracies, and how you will detonate the weapons.

One of the problems, I believe, is that many of the images we have of the nuclear winter effect generally seem to assume that the detonations are always on the downtowns of every large city. Why anybody would want to hit city hall, I don't know. From the military point of view, such targeting is absurd.

You may do collateral damage to a city by hitting some outlying parts of a city, but it is a different thing from so-called burning down the central city unless someone is determined to burn down the banks because that is pretty much what there is in the city center.

So, one has to review these things and targeting should be reviewed possibly from the nuclear winter point of view to see how one can further minimize the danger of creating an effect.

However, if you have an effect for belligerent countries—let me point this out. There will be a catastrophe, whether you have nuclear winter or not, for Third World countries in terms of food supply, medical supplies, even if it is only conventional war, if they cannot have access to these resources.

From the standpoint of the belligerent countries, the issue is really that a nuclear winter effect of a few weeks in the midst of this destruction we have postulated is relatively of little significance. Remember, in order to have a nuclear winter effect, you have to attack precisely population targets in order to have the necessary amount of smoke. You wipe out an awful lot of people in this process. You are destroying the crops with fallout. At that point a nuclear winter effect of a few weeks or a month is irrelevant. It is hell for other people, but for people subjected to this, this is the least of their worries.

Senator **Quayle**. Let me ask one other question of this panel along the lines that Senator Wilson brought up.

I would like to get some comments on the TTAPS study and the accepted validity, the accuracy, the statements that are in that study, whether there are disagreements, whether this ought to be accepted at face value.

I think Senator Wilson pointed out Freeman Dyson has serious reservations about it and made some rather disparaging remarks about the study.

I am curious about your reaction to this study.

Dr. Gillespie, do you want to go first on that?

Dr. **Gillespie**. Yes.

First, with respect to the comments that Freeman Dyson has made, I am a little bit baffled by that because I have had one conversation with him on that subject and I did not get that flavor at all. So, in attempting to respond to Senator Wilson's question, I will try to find out a little bit more about what his real concern is, try to penetrate that a little bit more.

As to the TTAPS study, for what it was, it was very good, I think. Most of the other technical people that I have talked to thought the study is just fine. It was an initial estimate by not a large group of people, an initial look at a very complex problem.

It was admittedly a one-dimensional model that they used to predict effects. They did a wide variety of scenarios. I only discussed, I believe before you came in, the baseline scenario that they used.

Given their assumptions, I or anyone else would have arrived at the same conclusion.

Now, the question is, are all their assumptions, their two dozen input parameters or however many there really are, are they all right?

Well, the authors of the TTAPS articles themselves caveat the uncertainties. We have looked at some of the uncertainties, only a few of them. Some of the uncertainties have gone in such a direction as to lessen the effect. Others have made the effect potentially worse.

It is just far too early to make a final prediction. They have said here is something that is plausible. They were correct, it is plausible. We are not trying to decide how plausible and to quantify the effect in much more detail.

Senator **Quayle**. Anybody else want to comment on the TTAPS study?

Mr. **Sloss**. I am not competent to comment on the scientific aspect. It is hard to be critical of the scenarios because they have a whole slew of scenarios; a baseline scenario, for example, which has 5,000 megatons on urban areas. Those 5,000 megatons would create most of the fires.

I do not really consider it to be a very representative scenario. It seems to me it is not the most representative scenario from which to study this phenomena.

That is not to say it would not happen. It is a very large attack indeed when you consider that the average yield of U.S. weapons is about 150 KT. It takes a few of those to get up to a megaton. Five hundred megatons takes a lot of weapons. You have to be awfully anxious to hit the downtown bank that Dr. Goure talked about.

Senator **Quayle**. Dr. Harwell?

Dr. **Harwell**. With respect to the validity of the TTAPS study, I think that the National Academy of Sciences report which came out at the end of last year, the Carrier report, as well as the Scope study which has just now come out, have collectively included a very large number of sophisticated computer and mathematical analyses of the climatic phenomena associated with nuclear winter.

I think that it is clear from the diversity of these and the sophistication of the models, that it would be extremely unlikely to come to the conclusion that their basic physics are wrong in the TTAPS study.

Rather the other conclusion comes out which, as Dr. Gillespie said, considering the one dimensionality of the model and limitations of their initial approach, they were quite appropriate in what conclusions they were coming to.

The much more sophisticated models, the 3-D and interactive models, that have been used by a number of different groups, all support the clear plausibility of a severe climatic disturbance following a large-scale nuclear war.

I think it is important to get across that this sort of climatic response is not tied to any single scenario. There is a very wide range of nuclear war scenarios that give you the same sort of consequences.

What counts is how much smoke you can put in the atmosphere. One way of doing that is burning downtown urban areas. Another way is hitting fuel depots and oil storage facilities that can produce a tremendous amount of the type of smoke that has the optical properties that would lead to climatic effects.

While it is clear that in the TTAPS study there was a large number of scenarios looked at, these were done in the context of not saying we predict a nuclear war will look like this scenario or another scenario, but rather they were sensitivity analyses of what the effect would be if you had a war that did not hit cities or you had a war that only hit cities or you had a combination of surface and air bursts.

There were close to 20 different scenarios looked at. That is the approach that was taken, what the effects of changing the various parameters were.

It was impressive how robust the answers were to changing scenarios. The subsequent studies that have been done certainly reinforce that.

Dr. **Gillespie**. I feel forced to make one comment there because the term "robust conclusions" was just used.

I will just mention in the various scenarios in the TTAPS study when they looked at the 100 megaton, 100 cities burning scenario, they changed the ground rules. They increased the assumption as to the amount of smoke produced in order to keep the total amount injected roughly the same.

You have to look very carefully at the numbers here in order to understand the conclusions. Not only do I find the concept of a nuclear war wherein the attack is on 100 cities to be a rather implausible scenario, but laying that aside, I find the conclusion that burning 100 or fewer than 100 cities—you see nothing is specified, how much of them do you burn, for what cities do you assume that a nuclear weapon is just a match that starts the whole thing burning, or do you more appropriately perhaps relate the amount burned to the yield of the nuclear device—I find the statement that burning some handful of cities is almost sure to lead to the climatic catastrophe a rather suspect statement, a much weaker likelihood of occurence than what we see in the baseline scenarios, for example.

Senator **Quayle** [presiding]. Senator Levin, do you have some more questions?

Senator **Levin**. Thank you, Mr. Chairman.

I have a few additional questions.

Dr. Goure mentioned that nuclear winter effect on the victims of the nuclear attack would be somewhat irrelevant. I agree with that.

Dr. **Goure**. For the belligerent. I did not say for the others.

Senator **Levin**. You said it would be irrelevant for the victims. The real question is whether or not a first strike, an incapacitating, paralyzing attack, would destroy the aggressor as well as the victims?

I think that, at least, is part of the new element of the nuclear winter theory. That is the part I want to focus on for a moment because that is really what we have not looked at so much. I do not think that has seeped into our psychology.

That is that nuclear weapons could render themselves obsolete even if there were no capability of the response. If sufficient nuclear weapons were utilized in the first strike, the aggressor could be destroyed in that first strike even without a retaliation effort by the victim.

It seems to me that is a realistic possibility. Research is going to determine whether it is. You can't determine it definitively. You can determine whether it is likely. That has to change some strategy.

I would think the Soviets would want to know that. You say maybe they are not doing independent research. We do not know if they are or not. We cannot verify research. We do not know what research they are really doing.

But I would think they would damn well want to know whether a first strike against the United States would destroy the Soviet Union even without retaliation by the United States. I would think that is a significant bit of information that they would want to know.

The nuclear winter theory raises that issue for the first time. Until the nuclear winter theory came along, that really was not the issue. The issue was do we have enough to retaliate, would we retaliate against the Soviet Union?

Would they face something that would make attack on us suicidal?

Now, the issue is even if an attack is not suicidal, that is something which we have not really made part of our own strategic thinking.

I would hope when this research is completed that we would learn a lot more about that issue. It is going to affect what we do on arms control, what we do in terms of weapons production, whether we put more money in conventional or nuclear weapons.

It has major effects on that issue. That is the part I want to focus on.

Are we looking at various scenarios or just the 50-percent utilization scenario?

Dr. GILLESPIE. We certainly intend to structure or program, we have structured it, in such a way that it is not scenario dependent so that a user can, in essence, build his own scenarios.

Senator LEVIN. User of the——

Dr. GILLESPIE. I am sorry. I used a little jargon there. Anyone who is interested in doing their own research or developing their own ideas based on the theories and the information we are developing, if he does not like somebody else's scenarios, he can build his own.

Senator LEVIN. So, Mr. Sloss, if he thinks it is more likely that there would be a strike against silos and very few against cities, he could plug that in and he would get the response from your model?

Dr. GILLESPIE. Yes.

Senator LEVIN. If somebody else goes at this many command posts and this many cities, you can do the targeting and get a response from the model?

Dr. GILLESPIE. Yes.

Senator LEVIN. What is the timeframe creation of that model?

Dr. GILLESPIE. I think the research program is one of several years. I would hope that we will have reached some reasonable conclusion in the next 4 or 5 years certainly.

Dr. GOURE. Sir, the key issue for the Soviet Union concerning nuclear winter as a deterrent, as well as for the United States, is probably, as I tried to say in my presentation, not so much the severity of the nuclear winter effect, but rather its duration.

The initial destruction is going to be vast regardless. If the Soviet Union or the United States have no prospect whatsoever of recovering and a key issue in this respect is food production, if they are not going to be able to produce food, they will not survive as nations, whatever nations are left. In that case you are or should be deterred.

Now, concerning this particular question, the real duration of the phenomenon, its severity, or the degree of its severity, has really not yet been effectively examined. We don't know from the models of the present studies what is likely to happen.

Senator **Levin**. The sooner, the better because the obvious impact on policy as far as I am concerned, we are spending about $2½ billion and I happen to support SDI research with the hope that that might lead us to, conceivably someday to a new form of stability which might be better than the one we have now.

We are spending one-five hundredths of that on research on nuclear winter. If nuclear winter became something we were satisfied with in terms of reality, that could be a bigger deterrent to a first strike than SDI. That is the issue.

We have to focus on it, it seems to me. If we believed that nuclear winter is a correct theory, it becomes perhaps as big a deterrent to a first strike as SDI and we are spending one-five hundredths of the research funds on it.

Now, if we can spend more usefully, we ought to. If we cannot, we should not. We should not waste money. We should realize the implication of this theory in terms of deterrence, at least an incapacitating first strike which is the way I am phrasing it very carefully.

Thank you.

Chairman **Goldwater**. Thank you very much, Senator.

I have a question that Senator Warner asked we put to Dr. Gillespie. This is it:

Recent measurements of the amount of the soot in the atmosphere in the mid-Pacific revealed that at most a few percent of the smoke from real fires travel far enough to affect global weather.

How much more than the 100 megatons of soot would be required to achieve in reality the homogeneous darkness so widely publicized?

Dr. **Gillespie**. It is a good question. I wish I knew the answer to it.

I am not aware of the particular research that he is referring to. I can only comment that the ability of the atmosphere to cleanse itself is widely recognized.

Each week we inject into the atmosphere several million tons of pollutants. Several percent of what it takes under the baseline scenarios to create very severe nuclear winter effects are injected, several percent of that amount are injected into the atmosphere just in our normal activities every week.

I cite that as an illustration of the ability of the atmosphere normally to clean itself.

I will undertake to find out more about what Senator Warner was referring to and provide an answer on that.

Chairman **Goldwater**. Thank you very much, Doctor.

[The information follows:]

NUCLEAR WINTER AND ITS IMPLICATIONS

We are still evaluating the references concerning mid-Pacific soot measurements. However, it is clear that 100 megatons of soot lofted to sufficient altitude and widely distributed is sufficient to achieve the publicized homogeneous darkness. The problem is that we do not yet know with confidence, (a) how much soot is likely to be lofted from a given scenario, (b) how much and how fast the soot may be scavenged out of the atmosphere, (c) how uniformly distributed the remaining soot is likely to be, and (d) what the effective lifetimes of the soot would be. Certainly, the potential exists for severe climatic consequences, but many assumptions and scientific uncertainties remain to be fully explored.

Chairman GOLDWATER. In your testimony you talked about the denial of heat.

What percentage of, I will call it sun denial does it take to create a problem?

Dr. GILLESPIE. It is quite clear, I think, from what Dr. Harwell has had to say that it is a sliding scale. Even 10 or 20 percent, I think, would clearly create a major problem.

I think it is clear qualitatively that the more sunlight you deny, the lower the temperature, the greater the effect upon agriculture.

The real problem is going to be to quantify what that relationship is.

Chairman GOLDWATER. Do you think you can do that?

Dr. GILLESPIE. I think we can learn a lot more than we know right now. Part of that problem, of course, is the problem for the biologists.

Chairman GOLDWATER. What makes me such a great believer in the possibility of nuclear winter, is the eruption of Krokotoa. We did not think much about it, I was not around. We did not think much about it in those days, but that in effect caused a worldwide cover and even the recent eruption of the volcano in Washington had its effect over parts of our open country.

So, I do not like this subject to be laughingly pushed aside because I frankly think that if we ever get in a nuclear war, and I don't think we are going to, but if we do, the Soviets have over 10,000, we have over 10,000.

First of all, it would not make much difference about a nuclear winter, but we sure would have something.

Dr. Goure, in your testimony you indicate there is no evidence that publicized Soviet views on nuclear winter has had any influence on Soviet leadership views on nuclear war strategy and warfighting.

Could you continue further on this?

Mr. GOURE. Logically, it might affect Soviet views about investing in survival programs. It might affect Soviet views, for example, on the feasibility of nuclear war-fighting.

As to the rest of it, targeting concepts, reduction in weapons, pursuing small yield weapons or, as Mr. Sloss said, Earth penetrators; in other words, possible steps to reduce the nuclear winter threat, from that point of view, I could say that the Soviet military public writings, books and monographs and newspapers, have ignored this aspect of nuclear winter altogether.

As far as their talking about the Civil Defense Program, the issue of destruction of the population, civil defense measures, and so forth, they are all ignoring the nuclear winter effect and pursuing the standard, previously known Soviet strategic objectives such as victory, survival, protection, shelters, and this sort of thing.

True, it might be said that the nuclear winter hypothesis has not had much impact on the U.S. Government's defense policy either, but at least we have a great deal of discussion of its implications including its strategic implications or weapon implications, targeting implications, and so forth.

There is no such discussion in the Soviet Union and there is certainly nothing in public about it. Whether there is discussion in the classified area, we wouldn't know. It is possible that it exists. There is no evidence of it in the public area.

Chairman **Goldwater**. Sitting up here, I drew a circle of the globe. The prevailing winds in this hemisphere are coming out of the west generally.

What would happen to the Southern Hemisphere in case of a large-scale nuclear war in the Northern Hemisphere? Would they be affected?

Dr. **Harwell**. That is something that in particular we addressed in the Scope study because it was an international effort and we had a number of scientists from Australia and New Zealand who were especially interested in that question.

I think one of the important new findings is that the smoke generated from fires in the Northern Hemisphere is likely to reach the stratosphere, perhaps in very significant quantities. If that is the case, there is considerably more exchange of air in the stratosphere from the Northern Hemisphere to the Southern Hemisphere than there is in the lower atmosphere.

That is one mechanism by which smoke particles are likely to get into the Southern Hemisphere.

Now, there is a clear issue of seasonality. If the war were to occur during spring or summertime in the Northern Hemisphere, then the sunlight is more intense, the smoke is elevated to the highest level and it travels further to the south.

If the war were to occur during the wintertime, then the sunlight would probably not be enough to get the smoke into the stratosphere, and the Southern Hemisphere would wind up not having climatic effect.

Clearly, the Southern Hemisphere climatic effect would be considerably less than the Northern Hemisphere.

One, because it is further away, and a lot of the smoke would be deposited out before getting down there.

A second reason is that there is much more ocean in the Southern Hemisphere than in the Northern Hemisphere, and that buffers the temperature decreases.

One issue that we think may be very important in the Southern Hemisphere is disruption in precipitation patterns that could affect on a continent-wide basis, Australia is an example, where temperature decreases would not bother them, but if you reduce precipitation by a few tenths of a percent, that that could lead to severe consequences.

Chairman **Goldwater**. Thank you very much.

I have never heard that scientific fact, the higher you go, the better distribution of winds, if there are winds up there.

Dr. Harwell, another question for you.

The year without a summer in 1816 is often cited as an example of a small average temperature drop, presumably caused by volcanic effect with great consequences for agriculture.

What is known quantitatively about the extent of these climate effects and global consequences for agriculture?

Dr. **Harwell**. As Dr. Gillespie mentioned in his comments on the 1816 incident, we have to rely very much on anecdotal information. The studies that have been done of this suggest that throughout the Eastern United States and eastern Canada as well as in Western Europe there were severe impacts on agriculture production as a result of frost events occurring in June, July, and August of the year 1816.

In the Northern American areas, this did not lead to a food crisis because there was enough food in stores and alternative food sources available, but in certain parts of Europe, apparently this did lead to food imbalances and other sorts of indirect effects.

The issue of how much the average temperature decreased is not clear, but the studies I have seen of this suggest that it is in the range of less than 1 degree below normal temperature for that year if you average it over the summer, average it over the Northern Hemisphere.

The average temperature decrease in 1816 was very small. Yet it did lead to significant crop losses in both North America and Europe.

Chairman **Goldwater**. Thank you.

Mr. Sloss, you suggest in your testimony that it may be possible as we learn more about nuclear winter to make adjustments in our war plans to minimize climatic effects.

Now, without getting into classified information, can you speculate about the nature of such a change in war plans?

As I say, if it is classified, forget about it.

Mr. **Sloss**. As you know, we can't go very far in this classified area, but I can generalize.

As I said in my testimony and pointed out earlier, while many military targets are away from cities and away from forests where you might get fires, some military targets are co-located in urban areas, an example being barracks for troops and command centers. As we learn more about the phenomenology, it seems to me that we have to consider very seriously a tradeoff, particularly as there is no single target that is likely to be vital in the success of our war plans.

By the way, it is not a new idea. We do have guidelines for avoiding cities under certain conditions at the present time. Here we are concerned about the direct effects. Thus, if we are considering a limited strike against military targets, guidelines would permit us to limit the effect of that attack on cities. We haven't in our planning up to now taken into account the fire effects in the same way.

One of the things we might do is change the actual point at which we put down the weapon or we might actually come off certain targets if we thought the consequences of striking that target in terms of potential for nuclear winter effect would be more severe than the benefits that we might get.

Chairman **Goldwater**. Senator Cohen?

Senator **Cohen**. Dr. Goure indicated that the Soviets pay very little attention to their scientists.

I am not sure that our scientific community has more impact on our military planners than the Soviet scientists have on theirs.

Assuming you are correct, they have done very little in the way of actual research on the phenomenon of nuclear winter and have tried to exploit its propaganda value, I was wondering how that pertains to the analysis?

Dr. Gillespie, you indicated a lot would depend on the type of weapon, yield, targeting.

If the Soviets have so little concern about nuclear winter, then does it follow from that that they would have higher yield weapons, that they in fact would have no compunction about hitting cities?

We might raise the moral issue about how immoral it is to target cities and, therefore, renounce the doctrine of mutual assured destruction, but I am not sure that the same thing would apply to them.

To the extent they attack silos—ours are not nearly as hardened as theirs—would they have incentives against hitting cities?

Would that change your analysis of the smoke loading factor if they target our cities in the United States as well as our missile silos?

Dr. **Gillespie**. The baseline cases I refer to have built into them the assumption of the fact that both the Soviets and we may make major attacks on cities. That assumption is already made.

Senator **Cohen**. I got the impression that you assumed that the bulk of the weapons would be directed toward counterforce targets and not directed to cities?

Dr. **Gillespie**. More specifically the TTAPS study, let me cite that, assumes that 4,000 megatons is directed against counterforce targets, if you will, and 1,000 megatons is directed against cities.

That resulted in the burning of about one-third of all the urban areas in the Northern Hemisphere.

Senator **Cohen**. The report that was issued by the Department of Defense indicates, pages 7 to 8, that there is a research agenda to be followed by DOD, DOE, and other involved agencies and that the research done by DOE is fully coordinated with that of DOD.

In your judgment, is that correct, is it fully coordinated?

Dr. **Gillespie**. Yes, sir, it is.

Senator **Cohen**. Was that done before the research was undertaken or only after the study?

When is that coordination done?

Dr. **Gillespie**. It is being done continuously through several mechanisms. I should say that the research that we are going to do is being coordinated now.

Senator **Cohen**. How much is being spent each year in that effort?

Dr. **Gillespie**. The total national program is $5.5 million, $2.5 million each from the Department of Energy and the Department of Defense, $500,000 from the National Science Foundation.

Senator **Cohen**. Now, the Defense Science Board in the draft national program plan recommended spending $10 million a year for 5 years as a minimal amount required for Federal scientific effort.

Dr. **Gillespie**. I am not aware that the Defense Sciences Board made a recommendation of any sort. The $10 million a year for 5 years you refer to was one of—let me put it this way, that was a bit of advertisement by certain people before the fact.

There were a lot of numbers talked about, but there was never a specific recommendation as to a particular amount.

Senator **Cohen**. Dr. Gillespie, you touched on a point in the initial part of your testimony which I think is of some importance and that is the insecurity of the Southern Hemisphere.

As you know, there is a good deal of movement in some of the nations like New Zealand and others to have a so-called nuclear-free zone in the South Pacific.

I think you indicated there is no such thing as a nuclear-free zone in terms of consequences of a significant exchange between the United States and the Soviet Union, that areas as far remote as New Zealand would still be impacted. I think, Dr. Harwell, you indicated that the indirect consequences would be more severe to India and Africa than perhaps the United States and Soviet Union.

So, it is fair to say it is global in its consequences and not confined to the Northern Hemisphere.

Dr. **Gillespie**. Certainly we are not seeing any major temperature changes or even minor temperature changes as far south as New Zealand, even in the worst cases.

There is a possibility that there will be changes, alterations to their weather patterns and those can have certain effects as Dr. Harwell has discussed. These kinds of effects are problematical. We will learn more about them.

I think one can predict with great confidence that they will be affected by other effects independent of any effect on the climate. That is to say, cessation of the normal infrastructure that supports agriculture, normal trade and economic interchange.

Those kinds of effects are, I think, almost certain to occur as the Scope study points out.

Senator **Cohen**. One final question.

We talked in terms of biological consequences, but we did not focus particularly on what the effects would be of radiation of the soil. You are talking about an exchange of 10,000 or 12,000 nuclear warheads.

Was there any analysis done of the long-term effect on the soil with that amount of radiation?

Dr. **Harwell**. The key issue for radiation is the number of surface detonations that occur. If you had a nuclear war and there were no surface detonations, the type of fallout you get would not cause biologically significant impact, by and large.

If you have a large number of surface detonations, you get local fallout that could have high levels of radioactivity.

In terms of the aerial extent of that, such as decreasing the availability of land for agriculture, it is a problem, but it is by far a smaller problem than other impacts on agriculture including climatic effects and including disruption in energy subsidies, and so on.

One interesting additional set of calculations that were done just as a test of what the consequences would be was looking at the impact of nuclear power facilities being targeted, especially not nuclear power plants, but especially fuel storage areas or reprocessing plants.

Were they to be targeted, the area of superlethal levels of radiation increases very much over large parts of the United States and Europe and western Soviet Union.

If you add in those types of scenarios, there is a possibility of very long-term contaminations; the radioactivity associated with nuclear power facilities is much longer lived, by and large, than what is associated with nuclear detonation.

Senator COHEN. I notice you are shaking your head, Dr. Gillespie.

Dr. GILLESPIE. Well, I cannot accept that conclusion. The reason is the following: That fuel from nuclear power plants, in a nuclear power plant is extremely well protected. In order to damage the environment, you would essentially have to vaporize it.

In targeting of nuclear facilities, you may target them with several psi overpressure and totally destroy them. By no means, however, does that lead to any significant dispersal of the fuel in those powerplants.

I believe the NRC has looked at that and has made some estimates as to what the extent of that would be. I am not familiar with that study, but I believe it supports sort of the general trend of what I say.

You have to remember that nuclear fuel rods are designed to withstand very tremendous levels of heat and pressure and those levels are far in excess of what it takes to destroy the facility, whether it is a nuclear power plant or a reprocessing plant that may contain those fuel pellets.

Certainly at a reprocessing plant there will be some amount of material that is not a part of fuel rods at any given time in the process and I could readily believe that that would be scattered around and increase the levels, but I do not believe it has the very severe consequences of greatly increasing what you have from the initial nuclear explosion itself.

Chairman GOLDWATER. Gentlemen, I can't begin to tell you how interesting this morning has been, one of the most interesting meetings I have attended in all my years here.

I really believe that it touches on a subject that we do not want to see too much noise made about without more knowledge, but it is something I think that the American people should be well aware of.

My personal feeling is that the climatic results of any prolonged nuclear attack would be far more disastrous than the actual effect of the weapon.

So, thank you very much for coming. We certainly appreciate it.

The meeting is adjourned.

[Questions with answers supplied follow:]

QUESTIONS SUBMITTED BY SENATOR JOHN WARNER

NUCLEAR WINTER AND ITS IMPLICATIONS

Senator WARNER. As I understand your testimony, a major uncertainty regarding nuclear winter has to do with our current inability to quantify the phenomena involved. Can you summarize for the committee what quantifiable data is available, for example from atmospheric testing and large fires, and what this data suggests relative to the potential magnitude of climatic changes?

Dr. **Gillespie**. The data available from extremely large historical fires, such as those produced at Hamburg, Dresden, and Hiroshima are anecdotal at best, and no conclusions concerning the likelihood, or lack of same, relative to the suggested climatic changes in the nuclear winter scenario can be drawn. There are some relevant data available from studies of radioactive particle dispersion taken during the atmospheric testing days, and from such natural events as volcanic explosions which may inject dust into the atmosphere, and from studies of the transport of pollutants through the atmosphere, but, on the whole, the relevant data are much too sparse at present to give any insight into the validity of a nuclear winter scenario.

Senator **Warner**. What are the most important biological problems for research to reduce the biological uncertainties associated with nuclear winter?

Dr. **Harwell**. It is important to recognize that there is an overriding endpoint for research on the consequences of nuclear war, specifically, the potential impacts on humans and society. The consequences to the global human population are precisely what a research program should focus on; all the other considerations of the effects of nuclear war are merely intermediary steps in making that evaluation. Consequently, results from the physical and atmospheric scientists provide just the initial conditions in assessing the effects of central concern to us.

The ENUWAR study came to a number of conclusions concerning the biological effects of nuclear war, including:

Effects on *ecological systems* would depend on the time of the year, the type of ecosystem, and the intensity of climatic and other physical stresses. Potentially these could involve virtually every type of environmental problem on a scale and intensity unprecedented in history, and impacts could be devastating and long-lasting.

Effects on *agricultural systems* of the Northern Hemisphere would be extreme, and agricultural production could be lost for at least the first growing season following a nuclear war.

Effects on *food availability* from disruption in agricultural production and distribution systems could lead to global-scale deaths from starvation.

Effects on *societal systems* could severely impacts the global human population. The remaining uncertainties, and, therefore, the research needs, differ among these topic areas, so I will address each separately.

(a.) Effects on ecological systems.—The analyses of potential effects on ecological systems are based on an extremely limited data base. This is simply because it had not been considered useful previous to the idea of nuclear winter to experimentally subject plants and animals to subfreezing temperatures and darkness. Thus, most of the physiological-level information base is on much milder stresses to biota than could occur in a nuclear winter. Further, even these experiments typically have been on single organisms, and very little has been done with whole ecosystems or with experimental microcosms. Similarly, most ecological models have been designed to respond to relatively mild changes in physical conditions, reflecting limited historical experience with conditions approaching nuclear winter.

Because of this, the ecological conclusions to date are based largely on expert judgment and on extrapolations from empirical data; consequently, there are many uncertainties about how biological organisms actually would respond. Even more importantly, ecological systems are extremely complex, and there is a general tendency for effects on one type of plant or animal to be propagated to many other species. Thus, predictions of the full range of biological impacts that could occur in ecological systems are highly uncertain. In addition, the presence of multiple disturbances occurring simultaneously (e.g., climatic changes, radiation, ultraviolet light, etc.) offers the potential, even the likelihood, of synergistic effects, where effects from combinations of stresses are worse than if the effects occurred independently. Whereas it is clear that ecological impacts would be substantial, the particular species that would be affected and the patterns of ecological recovery that would ensue cannot be reliably predicted at present.

To reduce these uncertainties, research is needed, both experimentally and in model development. Experiments need to be conducted on a large variety of organisms at different times of their life cycles and in response to different combinations of stresses. Microcosm and whole ecosystem experiments are essential in addition to the simple physiological experiments. Critical species or life stages need to be examined experimentally, such as the responses of important functional components of ecological systems (e.g., primary producers, decomposers), and such as the vulnerability of regenerative bases (e.g., seed and seedling banks). The latter is especially important in characterizing recovery prospects.

Model development needs particular emphasis in a nuclear winter research program, especially for models of different types of ecological systems with respect to productivity, species composition, and the effects on these of nuclear winter disturbances. This is essential since it is not possible to test each and every ecological system experimentally, but computer simulation models can be used to evaluate effects on the variety of environments.

In addition to nuclear winter, other potential stresses from nuclear war require research for their ecological impacts. Essentially no research has been done on this since the work in the early 1960's on the effects of external radiation on forests. The fate, transport, and effects of radionuclides on ecological systems needs concerted attention, especially in the context of the pathways that radionuclides would follow through the environment to humans. This source of internal radiation, through consumption of contaminated food and water, is probably as important to humans after nuclear war as external doses would be, but there has been very little research on this area.

These comments on ecological research needs are not meant to be comprehensive, but, rather, to give a sense that there is a tremendous number of questions that have not been addressed, and yet the potential effect of nuclear war on the environment is the most important environmental issue ever to confront us. There is the potential for very significant spin-offs from research on the ecological effects of nuclear war: Just as the studies of nuclear winter provided incentives and funding for the development of general atmospheric circulation models and other techniques for understanding climatic systems, which is of considerable general interest outside of nuclear war considerations, nuclear war-induced stresses on the environment provide an ideal framework to develop the general field of stress ecology. This field is in its infancy and is greatly in need of an infusion of resources and new ideas; yet it is an area of great importance in the current affairs of the citizens of the world in coping with increased anthropogenic disturbances to the environment, from acid precipitation and air pollution, to habitat destruction and loss of tropical forests, desertification and the causes of the environment disaster in Africa, and long-term global warming in response to increased levels of CO_2. Each of these issues, and a plethora of others, all require understanding of stress ecology to characterize their likely effects and the policy options that should be considered; each of these issues would benefit greatly by a concerted research program on the ecological effects of nuclear war.

(b.) Effects on agricultural systems.—The ENUWAR study also relied on physiological data, models, and historical experiences for inferences about nuclear winter effects, much as for the ecological effects. However, the conclusions that we were able to come to have much less uncertainty than do specific projections of ecological impacts. This is because of two reasons: 1.) agricultural systems are much more sensitive to climatic and other disturbances than are most ecological systems; since the range of projected climatic responses is largely above the levels necessary for devastation of agricultural production, the agricultural responses are clearer; and 2.) agricultural systems are far simpler than ecological systems, so that we can concentrate on a very limited number of species and do not have to contend with propagation of effects. Consequently, uncertainties about agricultural impacts are largely tied to uncertainties about the spatial extent, intensity, and duration of adverse climatic conditions.

Nevertheless, there are some issues concerning agricultural effects that require further research. With respect to nuclear winter effects, these include: experimentation of physiological responses of crop plants to climatic and other physical stresses, especially simultaneous ones; improvement of models relating crop productivity to physical conditions; simulation of additional types of crops and for additional locations than previously done; and research on effects of reduced sunlight levels and daylengths. Other nuclear war-induced impacts on agricultural production that need further investigation are: effects of radiation on crops and livestock, and the pathways for doses to humans through agriculture; effects of ultraviolet radiation, air pollutants, and other stresses, alone and in combination, on production; effects of disruptions in energy subsidies to agriculture (e.g., loss of fertilizers, pesticides, irrigation, etc.); and interactions with ecological effects, such as increased outbreaks of pests. Again, this list is not exhaustive.

(c.) Effects on food availability.—The uncertainties in the conclusions reached by the ENUWAR study for the potential for mass starvation relate to a few key issues: 1.) the levels of agricultural productivity that would follow a nuclear war; 2.) the amounts of food in storage in various countries, including its current locations within the countries; 3.) the levels of food exports and imports that would occur; 4.) the distribution of food reserves among the survivors of the immediate effects of nuclear detonations; and 5.) the length of time before agricultural production could be resumed at levels sufficient to maintain the surviving population. The results to

date have had to rely on a mix of worst-case and best-case assumptions; for instance, assumptions of having no agricultural production or food imports at all, but simultaneously having perfect distribution of food to survivors. Further research is needed to refine those analyses, by examining an expanded range of scenarios and assumptions (i.e., sensitivity analyses), and especially by looking more closely at individual countries with respect to their food stores, distribution, and requirements.

(d.) Effects on societal systems.—To date, there have been no major studies on the direct and indirect effects of a large-scale nuclear war on societies in combatant and non-combatant countries. Yet I believe there is the potential for very significant effects on survivors mediated by such societal effects. One indication of the potential vulnerabilities to societal effects are the sensitivity analyses we have done concerning the occurrence of less-than-perfect allocation of food resources among survivors, which indicate, for instance, that hoarding of food by only a few percent of survivors could lead to the disproportionate loss of others. There is a large number of issues relating to societal effects, including effects on political, military, and economic systems; effects of competition for limited resources needed for survival; psychological responses of individuals and groups of people; interactions among post-war countries; and prospects for long-term recovery. There is no historical precedent of the scale or magnitude of disturbances to society from nuclear war; nevertheless, analogs can be examined for inferences (e.g., examples from wars, disease epidemics, natural disasters, etc.). Going beyond the extrapolations from such analogs will require a concerted research program involving appropriate scientists. In my opinion, such research is critical, as societal impacts of nuclear war constitute the single most important scientific issue that remains to be addressed in any depth.

Beyond these considerations, of research on ecological systems, agricultural productivity, human subsistence requirements, and societal responses, is the clear need for independent, objective analyses of the policy implications of nuclear winter. Along with societal effects, the policy implications have to date received essentially no serious attention; yet for those of us who have followed the development of the new perspective of nuclear war (i.e., of the greater potential for indirect effects on human populations, even in non-combatant countries, than the direct effects of nuclear war), it seems apparent that policy implications exist for the full gamut of nuclear weapons issued. We believe that a fundamentally different picture of global effects on peoples of non-combatant and combatant countries alike must become the new standard perception, permeating thinking about nuclear policies throughout the world, if the visions portrayed in the ENUWAR study are to remain just intellectual exercises and not the irreversible future of humanity.

Senator **Warner**. From the analysis that has been accomplished to date, does the nuclear winter hypothesis in your judgment call into question the fundamental components of our targeting policy, particularly the emphasis on escalation control?

Mr. **Sloss**. From what we have learned to date about nuclear winter, I see no need to alter the fundamental components of our nuclear targeting policy which has evolved over the past twenty years under five administrations. As to escalation control, there are many uncertainties. Nuclear winter adds another uncertainty to the many that already exists with respect to nuclear war scenarios. I believe there is no choice but to plan as best we can to try to control escalation. The alternative of not planning to control escalation would be far worse.

Senator **Warner**. Are there areas where the Soviets might make a useful contribution to the understanding of the nuclear winter phenomenon?

Dr. **Goure**. It is desirable to distinguish between two areas of inquiry concerning the nuclear winter phenomenon. The first, which is the key to the entire issue, studies the potential characteristics of the phenomenon itself, i.e., the emissions from mass fires; the amounts and characteristics of soot particles, their behavior and effects on sunlight; the modeling of global atmospheric circulation and distribution of smoke; scavanging mechanism; and so on. On the basis, the studies seek to predict the atmospheric and climatic consequences and their severity and duration resulting from various possible nuclear exchange scenarios. The second area studies the possible ecological, biological, and other environmental consequences of various nuclear winter effects as these are identified by the first set of studies and models.

Concerning the first area of investigation, U.S. scientists had hoped that Soviet scientists could contribute independent values to the essential parameters characterizing soot and other particles lofted into the atmosphere by nuclear detonations and fires and also contribute to the modeling of global atmospheric circulation. On November 1, 1983, at a public meeting on nuclear winter held in Washington, D.C., Dr. Carl Sagan asked Soviet scientists during a closed-circuit TV link with Moscow:

"Do our Soviet colleagues think it is possible that they might supply data on the particle size distribution function of debris from Soviet nuclear weapon tests before the 1963 Limited Test Ban Treaty, and information on particle sizes and absorption coefficients from large fires in the Soviet Union? Also, will they eventually give us a range of nuclear war scenarios that they consider likely?"

There has been no Soviet response to this request. In 1984, U.S. scientists had been given to believe that the Soviets may conduct some large fire experiments. However, at a joint U.S.-Soviet scientific meeting held in Moscow during August 13–17, 1984, Dr. N.N. Moseyev, deputy director of the Computing Center of the USSR Academy of Sciences, indicated that the Soviets had decided that the modeling of massive fires is too difficult for them to do and, essentially, that their computers cannot adequately deal with all the complexities. The impression of the U.S. participants at this meeting was that the Soviets had put fire research on hold.

In 1984–1985, to the extent that one can speak of a Soviet contribution to nuclear winter studies, it has focused on a relatively minor Soviet finding said to have been discovered by Soviet scientists during Soviet atmospheric nuclear tests. This finding, usually presented by Professor K.Ya. Kondratyev of the Lake Study Institute of the USSR Academy of Sciences, concerns the cooling effect of nitric dioxide (NO_2) generated by nuclear detonations, which may lower temperatures by a few degrees. It should be noted, however, that effects of dust and NO_2, while contributing to climatic effects, are considered to be adjunct to the nuclear winter phenomenon proper, which depends primarily on smoke and soot injected into the atmosphere by fires.

Another area of apparent major Soviet interest concerns the question of possible depletion of the ozone layer as a consequence of large nuclear detonations. This has received a great deal of attention in the Soviet Union. The ozone layer depletion issue was extensively analyzed by U.S. scientists during the 1970s. It is possible, however, that Soviet scientists may make a further contribution to this study area, which, however, is tangential to the nuclear winter issue.

Soviet scientists also claim to have made independent studies of the effects of the Tunguska meteorite strike in 1908 and assert that their findings are at variance with those of Dr. Turco and other U.S. scientists.

U.S. scientists believe that the Soviets could make a useful contribution to the study of the nuclear winter phenomenon in the fields of aerosol physics and of optical properties of the aerosols generated by nuclear detonations and fires. They also hope that the Soviets can still be persuaded to undertake large fire experiments. The most recent Soviet simulation of a nuclear winter shows improvements in the Soviet approach to such modeling. However, the findings essentially duplicate those of recent U.S. studies which indicate a less severe effect than was believed to be the case on the basis of the earlier TTAPS model. It is doubtful, however, that the Soviets are in a position to make a significant independent contribution in the simulation of the nuclear winter phenomenon.

Undoubtedly, the Soviets could contribute to studies of the ecological and biological consequences of nuclear winter and, indeed, have done so to some extent. However, as in the case of research by Western scientists in this area, the projections of the consequences of nuclear winter continue to critically depend on exchange scenarios and the modeling of their climatic effects. The tendency of Soviet scientists to base their estimates on worst-case scenarios has the effect of interfering with an objective assessment of the ecological and biological consequences of nuclear winter.

Overall, it can be said that from a practical standpoint Soviet contribution to the study of the nuclear winter phenomenon has been marginal and is likely to continue to be of this character. All too often this is overlooked in the enthusiasm of U.S. scientists for contacts and cooperative activities with the Soviet scientists, especially when it comes to studies of the various possible consequences of a nuclear war.

QUESTIONS SUBMITTED BY SENATOR WILLIAM COHEN

CONTRIBUTION OF FIRE IN ACHIEVING TARGETING OBJECTIVES

Senator COHEN. Discussion at last month's National Academy of Sciences symposium addressed the effects of nuclear explosion-produced fires. Mr. Sloss stated in his testimony to the committee that "we have not yet taken into account the fire effects." Does the United States take fire effects into account in its targeting of forces or in other aspects of its planning? What nuclear weapons effects are taken into account in such planning? Could fires resulting from nuclear explosion significantly contribute in producing damage against targets?

Dr. GILLESPIE. [Deleted.]

Senator **Cohen**. If United States could reliably take into account the effects of nuclear explosion-produced fires, could we reduce the number and/or yield of U.S. warheads assigned to targets while maintaining the desired damage levels against those targets? Could this reduce overall U.S. nuclear force requirements?

Dr. **Gillespie**. [Deleted.]

Senator **Cohen**. Has DNA or anyone else (e.g., OSD, JSTPS, Nuclear Targeting Policy Review, the national laboratories or FCRC's) analyzed the possibility of modified weapon or force requirements resulting from the incorporation of U.S. planning of fire or other non-blast effects?

Dr. **Gillespie**. [Deleted.]

Senator **Cohen**. Is DNA or anyone else attempting to quantify these fire effects and determine their reliability as a source of damage? If we can quantify such fire effects, can they be incorporated into U.S. planning?

Dr. **Gillespie**. [Deleted.]

Senator **Cohen**. Are there other potentially significant nuclear weapon effects which the United States does not take into account?

Dr. **Gillespie**. [Deleted.]

Senator **Cohen**. It is U.S. policy to enhance deterrence by developing weapon systems and plans that would minimize collateral damage. Do U.S. analyses of collateral damage resulting from nuclear conflict take into account nuclear explosion-produced fires? Would U.S. efforts to develop means to minimize collateral damage be advanced by taking this into account?

Dr. **Gillespie**. [Deleted.]

Senator **Cohen**. Dr. Theodore Postol, at the NAS symposium, stated that DOD estimates of nuclear war casualties are far too low because fires are ignored (this even assuming there are no "nuclear winter" effects). If fires were taken into account, would U.S. estimates of casualties increase significantly?

Dr. **Gillespie**. [Deleted.]

Senator **Cohen**. Dr. Richard Wagner stated, in a 6/4/85 letter to me: "We will augment research on the biological consequences of potential long-term temperature depressions. While this is a very difficult problem to resolve accurately, it is essential that we understand the mechanisms in sufficient detail to guide the research in climatic effects."

Has research on these biological consequences been augmented by DOD?

Dr. **Gillespie**. The DOE has begun preliminary research on biological consequences as part of the U.S. national program coordinated by OSTP. DOD is presently evaluating recently published findings on the biological consequences of nuclear winter scenarios published by other groups but has not, as yet, started any research.

Senator **Cohen**. Do you agree with Dr. Wagner's view that understanding the biological consequences is necessary to guide the climatic research? To what extent have the physical scientists involved in "nuclear winter"-related research consulted with biological and ecological scientists, to your knowledge?

Dr. **Gillespie**. Understanding the potential biological consequences may have impact on climatic research particularly as the climate research begins to produce more quantitative results for biological assessment. There has been a considerable and growing interaction between physical scientists and biologists and ecologists at various scientific meetings and symposia devoted to this subject.

BIOLOGICAL EFFECTS

Senator **Cohen**. Dr. Richard Wagner stated, in a 6/4/85 letter to me:

"We will augment research on the biological consequences of potential long-term temperature depressions. While this is a very difficult problem to resolve accurately, it is essential that we understand the mechanisms in sufficient detail to guide the research in climatic effects."

To your knowledge, has research on these biological consequences been augmented by DOD?

Do you agree with Dr. Wagner's view that understanding the biological consequences is necessary to guide the climatic research? To what extent have the physical scientists involved in "nuclear winter"-related research consulted with biological and ecological scientists, to your knowledge?

Dr. **Harwell**. To the best of my knowledge, the U.S. Department of Defense has not provided any significant funding for research on the biological issues associated with nuclear winter. There were discussions about a year ago of a larger national program for nuclear winter research that would include elements of biological research, but the plan that emerged was reduced to about $5.5 million, of which $2.5 million comes from each of the Departments of Defense and Energy for work primarily carried on by the DOE National Laboratories, and another $0.5 million from the National Science Foundation for research at its National Center for Atmospheric Research. All of this research funding is for research on the atmospheric and climatic responses to nuclear war.

To date essentially all of the work on the biological effects of nuclear winter has been funded by U.S. foundations, and that funding has been largely just for holding international conferences, rather than for conducting new experimental or modeling research. The modeling work that has been done has primarily involved donated resources of the individual institutions (e.g., modelling at Cornell and the University of Rhode Island). The only significant exception to the non-governmental support for this research has been the work supported by the Soviet Academy of Sciences at its Laboratory of Mathematical Ecology, which resulted in a 250-page technical report of ecological analyses. I believe that understanding the biological responses to climatic and other perturbations of nuclear war is an essential component in directing the climatic studies. There is a great opportunity for feedback from the biological analyses into the physical studies. For instance, many of the issues in dispute for climatic consequences involve the early, acute time period, with current arguments over the intensity of initial temperature decreases. Analyses of the concomitant impacts on agricultural systems, however, indicate that even for much smaller temperature decreases than in most of the climatic predictions, the effects on regional and global agricultural productivity would still be devastating. Similar responses can be expected for many natural ecosystems if affected during their vulnerable growing seasons, or should tropical and sub-tropical systems suffer freezing or chilling. Hence, much of the dispute over the levels of acute climatic responses would seem to be irrelevant to the central issue of overriding importance: human survival. We are coming to the realization that the *duration* of climatic changes of a few degrees is more important, within limits, than how extreme the initial temperature drop would be; this indicates a clear need for longer-term climatic analyses. As another example, we recognize that extreme temperature excursions for quite limited periods can be extremely damaging if occurring in certain regions or in the active growing season; nevertheless, how *quickly* temperatures would drop and the nature of their temporal patchiness might be as important as how low temperatures drop. Duration of extremes are more important for ecosystems which are not adapted to or used to experiencing such extremes. The potential reduction in precipitation in the longer-term, chronic phase following a nuclear war appears to be biologically more important for many systems than the loss of incident sunlight during the acute period. The degree of spatial and temporal heterogeneity of climatic effects requires considerably more study. For instance, an average temperature decrease could occur by having each day's temperatures reduced by the same amount, or it could occur by having an increase in the frequency, duration, and/or intensity of brief episodes of cold temperatures; quite different effects could ensue from those two cases. Different issues are key for different regions, as seen by the biological analyses thus far; e.g., Australian agricultural systems are most vulnerable to changes in precipitation; pelagic marine ecosystems are most vulnerable to prolonged decreased light inputs; many agricultural systems and tropical ecosystems are most vulnerable to low temperature excursions. Other considerations are that external radiation doses anticipated from global fallout, which have been well investigated, are not very significant with respect to inducing human and biological effects; but local fallout and internal doses, which are rarely analyzed and are poorly understood, would likely be of critical importance to millions of humans and to natural and agricultural systems after a nuclear war. In summary, these and a large number of other findings from biological considerations need to be integrated into a physical effects research program in order to make it more relevant.

Biological responses can have direct feedback to the physical processes themselves. For instance, changes in biological systems on a large scale would likely affect surface albedo. The possibility of the creation of large areas of standing dead biomass from temperature-induced impacts on tropical forests leads to the consideration of massive fires extending into the several-year time frame, potentially prolonging climatic effects; similar fires can follow from coniferous forests killed by local fallout, and by grassland, forest, and other ecosystems subject to reduced precipitation. Further, biologically mediated processes affect or control many atmospheric processes, e.g., via changes in CO_2 inputs and sinks, changes in the rates of evapotranspiration, and the global cycles of other atmospheric gases. The biological record can be instructive in evaluating previous catastrophic events, especially those which have concerned periods of weeks, months, or years of lowered temperatures with frosts occurring in the growing season. Such climatic analogs, including the Little Ice Age and volcanic events, have been inadequately investigated so far. And human-ecological interactions, such as desertification resulting from overexploitation for resources, can extend climatic effects in time and space. Clearly, the feedbacks are many, and physical analyses will be incomplete and often less relevant without their consideration.

What if it were found that there would be no nuclear war-induced climatic perturbations? There are still many global biological issues resulting from nuclear war that require careful attention. The current arsenals of strategic nuclear weapons are so large that the effects seen at Hiroshima and Nagasaki are grossly inadequate as models of a modern nuclear war. Issues such as prompt fallout, UV-B enhancement, pyrotoxins, habitat destruction, acidic fogs, elevated NO_x and HCI levels, and fire-caused high CO levels, among many others, could affect the human and biological systems on a local or global scale. The potential for synergistic effects among these stresses is very high, but almost no work has been done in this area. Linkages of agricultural and ecological effects to impacts on human societal systems are extremely important; for example, reduced agricultural productivity from loss of fossil fuel subsidies alone could tremendously decrease world food yields, and disruption of food imports to many countries in the world could lead to large consequences even for humans far removed from the theatres of nuclear war. It is apparent that should major climatic disturbances occur, human consequences would be devastating; but the converse is not true, that minor or no climatic effects would result in only limited impacts on the global human population.

The initial research on nuclear winter had very little input from biological scientists in helping frame the relevant questions for research; rather, the results were fairly well established from this early work before the biological scientists were approached. However, the research that has been underway during the last year or so has involved biological scientists in a more substantial way; this was especially true for the International Council of Scientific Unions' ENUWAR study that was released in September, 1985. As a part of this study, a series of workshops were held, including conferences in London, Stockholm, New Delhi, Leningrad, Paris, Hiroshima, Tokyo, Melbourne, Essex, and Washington, at which both physical and biological scientists participated. At each of these, interactions between the two lines of analyses were explicitly sought, and the final ENUWAR report reflects this exchange of ideas and information; nevertheless, we would have liked for there to have been even greater integration of the two, and our research recommendations specifically call for enhanced linkage between physical and biological research programs.

Examples of the types of questions that the physical scientists have been asked to address in response to biological considerations are: longer-term climatic effects; greater attention to precipitation; questions about variances of climatic effects in addition to just looking at averages; greater attention to interactions with ocean systems; calculations of daylength under a nuclear winter atmosphere; potential for coastal storms; possible sources of air pollutants and acid precipitation; disruptions in monsoon development; greater attention to tropical and Southern Hemisphere conditions; and a general emphasis on more local scales of atmospheric systems. Biological scientists have also been asked about factors that could affect climatic effects, such as the potential for changes in albedo in response to large-scale mortality in forests; the potential for fires to develop and spread in natural and agricultural systems; and the potential for changed patterns of evapotranspiration.

However, with the conclusion of the ENUWAR project, there is very little biological research underway anywhere on the effects of nuclear war; the sorts of interactions that are required between physical and biological scientists cannot occur in the absence of a biological research effort.

Senator Cohen. Discussion at a recent National Academy of Sciences symposium addressed the effects of nuclear explosion-produced fires.

Does the U.S. take fire effects into account in its targeting of forces or in other aspects of its planning? What nuclear weapons effects are taken into account in such planning? Could fires resulting from nuclear explosions significantly contribute in producing damage against targets?

Did the Carter Administration's Nuclear Targeting Policy Review consider the possibility of including fire and/or other non-blast effects in targeting planning? If so, please describe the manner in which this was considered, issues that were raised, and conclusions reached.

If U.S. could reliably take into account the effects of nuclear explosion-produced fires or other non-blast effects, could we reduce the number and/or yield of US warheads assigned to targets while maintaining the desired damage levels against those targets? Could this reduce overall U.S. nuclear force requirements?

Are you aware of any analysis of the possibility of modified warhead or force requirements resulting from the incorporation in U.S. planning of fire or other non-blast effects?

Are you aware of any efforts to quantify these fire effects and determine their reliability as a source of damage? If we can quantify such fire effects, can they be incorporated into U.S. planning? If we cannot adequately quantify them, should we simply ignore such a potentially significant factor because it is too uncertain? What other uncertainties do we face in nuclear planning and how do we incorporate these into our planning?

It is U.S. policy to enhance deterrence by developing weapon systems and plans that would minimize collateral damage. Do U.S. analyses of collateral damage resulting from nuclear conflict take into account nuclear explosion-produced fires? Would U.S. efforts to develop means to minimize collateral damage be advanced by taking this into account?

Dr. Theodore Postol, at the NAS symposium, stated that DOD estimates of nuclear war casualties are far too low because fires are ignored (this even assuming there are no "nuclear winter" effects). If fires were taken into account, would U.S. estimates of casualties increase significantly?

Mr. SLOSS. It would not be appropriate for me to talk about our current targeting policy. I am not fully informed any longer as to the details of that policy, and of course many details are highly sensitive. It would be more appropriate to ask someone from the administration to discuss current policies and targeting criteria. However, I am prepared to state some personal views about fire as a damage mechanism.

I think it is likely that in any large-scale nuclear exchange, particularly when cities are attacked, there will be large and destructive fires. These are likely to add to the damage created by blast. Unfortunately, despite a number of studies, we do not know exactly how fires will spread and, as a result, it is very difficult to predict how much additional damage fires will create beyond the damage created by direct blast, which will be substantial. There are uncertainties about blast damage as well, but I believe the uncertainties about the effects of fire are greater. For this reason, blast damage and prompt radiation have normally been the principal damage criteria used in targeting.

During the Nuclear Targeting Policy Review we did consider fire damage, but the testimony given us at the time suggested there were great uncertainties about the effects. We did not seriously consider fire as a *principal* damage mechanism, but rather as a possible additional effect; we also considered issues related to unwanted collateral damage from fires and other non-blast effects.

It is my own view, although I have no specific evidence to back this view, that taking more explicit account of non-blast effects (if we knew how to do so) would not significantly change weapons requirements, providing the same degree of confidence in achieving damage was required. Indeed the main problem with relying on fire as a principal damage mechanism is that effects cannot be assessed with high confidence due to the many uncertainties with respect to how fires start and are propogated. It is possible that further study could reduce these uncertainties, just as further study of nuclear winter could reduce uncertainties. This could contribute to the objective of minimizing collateral damage. However, from what I have seen of past studies I am skeptical that we can reduce these uncertainties very much.

There also are uncertainties relating to blast effects, stemming from an inability to estimate precisely the yield, accuracy and reliability of weapons. We attempt to narrow these uncertainties by testing and, where the target is very important, by allocating more than one weapon to it. Accuracy, which is particularly significant in determining weapons effects (far more so than yield), has a built-in margin for error based on a probability function (CEP).

Finally, as to Dr. Postol's estimates, I am just not sure. The additional casualties produced by fires will depend a great deal on the scenario and the targets attacked, and especially the extent to which fires extend beyond the area of prompt effects.

[Whereupon, at 12:15 p.m., the committee adjourned, subject to the call of the Chair.]

NUCLEAR WINTER AND ITS IMPLICATIONS

THURSDAY, OCTOBER 3, 1985

U.S. SENATE,
COMMITTEE ON ARMED SERVICES,
Washington, DC.

The committee met in open session, pursuant to notice, at 3 p.m., in room SD-562, Dirksen Senate Office Building, Senator Barry Goldwater (chairman) presiding.

Present: Senators Goldwater, Warner, Cohen, Wilson, Denton, Nunn, Hart, and Glenn.

Staff present: James F. McGovern, staff director and chief counsel; Arnold L. Punaro, staff director for the minority; Christine C. Dauth, chief clerk; Robert E. Bayer, Robert G. Bell, Robert F. Bott, Douglas R. Graham, William E. Hoehn, Jr., George K. Johnson, Jr., Russell E. Milnes, and Carl M. Smith, professional staff members; Colleen M. Getz, research assistant; and Karen A. Love, staff assistant.

Also present: Gerald J. Smith, assistant to Senator Goldwater; Robert P. Savitt, assistant to Senator Cohen; James M. Bodner, assistant to Senator Cohen; Mark J. Albrecht, assistant to Senator Wilson; Deforest Hamilton, assistant to Senator Denton; Alan Ptak, assistant to Senator Gramm; Janne E. Nolan, assistant to Senator Hart; John Keeley, assistant to Senator Levin; Gregory B. Craig, assistant to Senator Kennedy; and Phillip P. Upschulte, assistant to Senator Glenn.

OPENING STATEMENT BY SENATOR BARRY GOLDWATER, CHAIRMAN

Chairman GOLDWATER. The meeting will come to order.

This afternoon the committee meets to continue to receive testimony on the nuclear winter hypothesis.

Yesterday the committee heard testimony from administration and outside witnesses that provided a current assessment of the scientific findings with regard to nuclear winter and related phenomena.

We also received testimony on the targeting policy implications, as well as an indication of Soviet contributions to and their use of the nuclear winter hypothesis for propaganda purposes.

As I indicated at the conclusion of that hearing, I found it one of the most interesting that I have attended in some time.

In contrast to yesterday's hearing, which primarily dealt with technical issues, we should have an opportunity this afternoon to explore the interaction of current scientific findings with our current nuclear policies.

We are fortunate in having as our witnesses this afternoon Dr. Carl Sagan and Hon. Richard Perle.

Dr. Carl Sagan, noted author and scientist, is perhaps, more than any other single individual, responsible for bringing the nuclear winter hypothesis to the attention of the American public and indeed to a worldwide audience.

Dr. Sagan, welcome to the committee.

We also welcome back Mr. Perle, who as the Assistant Secretary of Defense for International Security Policy is responsible for nuclear policy matters in the Department of Defense. Mr. Perle is no stranger to this committee, and I would like to welcome you once again.

Gentlemen, I will repeat for you what I stated yesterday, and that is that understanding the potential effects of nuclear war on our planet is of tremendous importance to me personally, and will be a matter of continuing interest to this committee.

There is no doubt in my mind, and I am sure that there is no doubt in the mind of anyone in this room, that a nuclear war could be a catastrophe of such great proportions that it absolutely must be prevented. That is what our deterrence policy is all about. This committee has supported that policy, and will continue to support deterrence of war through the modernization of our deterrent forces, both conventional and nuclear.

I believe it is important to have hearings like this so that the public, as well as Senators, can be informed about the state of science regarding these issues, which, as we learned yesterday, is one of considerable uncertainty, and about how our scientific understanding should affect our policy choices.

I commend Senator Cohen for his active role in bringing these hearings about.

Following opening statements that other members of the committee would care to make, I will ask Dr. Sagan to begin.

In the interest of time, I have asked our witnesses to limit their remarks to 10 minutes each.

With the concurrence of committee members, we will withhold questions until both witnesses have spoken, at which time I would propose an initial round of questions limited to 5 minutes for each member of the committee.

Before we proceed, I would like to note that the committee is advised that later this afternoon the administration has arranged for members of the intelligence community to provide Senators with a highly classified briefing on Soviet strategic defense activities.

This committee has already been exposed to this intelligence information. It demonstrates that unlike the United States, the Soviet Union has never abandoned strategic defense as an important element of their strategic posture. They continue to invest as much in strategic defense forces, including air defense, as they do in their strategic offensive forces.

In view of this, our SDI Program should be called the SDR—a Strategic Defense Response to the Soviet Strategic Defense Initiative. I must concur with Ambassador Paul Nitze's assertion that, "The Soviet propaganda line against SDI is as predictable as it is hypocritical."

I will ask Senator Nunn if he has any statement he would care to make.

Senator NUNN. Very briefly, Mr. Chairman.

I think these hearings are very important. I know Dr. Sagan has been an outstanding researcher in this area. He has published several papers. I am interested very much in what he has to say today.

I also look forward to Mr. Perle's testimony.

As you have so well noted, the policy of deterrence has been and continues to be to prevent any kind of war taking place and certainly a nuclear war. I think we can all concede that the effect of a nuclear war would be devastating. We are going to hear, I am sure, how devastating today.

I am particularly anxious to get Dr. Sagan's views and also Secretary Perle's views about findings, to the extent that agreement is reached here today or throughout the community, how these findings impact our present deterrence policy and plans for the future as well as the assessment about the Soviet Union and their own posture.

I appreciate, Mr. Chairman, your having these hearings and I look forward to them.

Chairman GOLDWATER. Senator Cohen?

Senator COHEN. Thank you, Mr. Chairman.

I have a statement I would like to enter into the record. In the interest of time, I will summarize a couple points.

First, I want to welcome Dr. Sagan and Mr. Perle and thank you in particular, Mr. Chairman, because without your support, yesterday's and today's hearings would not have been held. I appreciate your holding these hearings.

I think one of the elements that came through to me yesterday as I listened to the testimony is that military planners are required to supply us with statistics and graphs on what is needed, what we need more of, better of, but one factor seems to be missing most of the time and that is the human factor.

We tend to get caught up in the language of first strike and counterforce activities. Yesterday, for example, I believe it was testified that we contemplate, as far as our scenario is concerned, an exchange of between 10,000 and 12,000 warheads and what that would mean—several hundred million killed, possibly as many as 4 billion killed.

We heard testimony about the loss of or interruption of commerce. That is a nice way of phrasing it.

I recall being stuck in some gaslines in California during the oil embargo. I remember the hysteria that struck this country at that time with people being shot at gas pumps. I recall one man being burned to death because he was using a vacuum cleaner trying to siphon gas out of somebody else's car.

I think we tend to underestimate, if we take the human factor into account, what would happen to human civilization if a nuclear exchange should occur, and the consequences that flow from that, with the loss of fuel and food, and the means of survival.

I think there has been an attitude in the past, if not in the present, to cavalierly dismiss the theory of nuclear winter as some sort of leftwing propaganda that serves only the interest of the

Soviet Union. The argument is that deterrence will prevent nuclear winter, if there is such a thing as nculear winter. So goes the argument.

I believe we should ask the question: What are the consequences if deterrence fails? What are the consequences to human civilization and society? And what are the policy implications for our military planners?

That was the reason why the DOD authorization bill was amended to require a study to be done by the Department of Defense and which was submitted to us last March.

Frankly, Mr. Chairman, I was not pleased, or entirely pleased, I might say, with the study done by the Department of Defense. The first seven or eight pages I thought were quite good in that it did list a number of the uncertainties involved in the calculations of nuclear winter. But then it went on to simply engage in a rather vigorous defense of strategic modernization and SDI and basing it entirely on deterrence.

What we really want to know is what are the policy implications if deterrence fails?

I note that one study was done by the Palomar Corp. for the Defense Nuclear Agency which, I think, raised interesting questions. I will take a moment just to raise these.

They asked, based on the factors identified by the TTAPS study: "Should the United States identify, categorize, and set priorities for military targets based on their smoke and dust creating potential and their colocation with such areas?

"Should plans be reevaluated for attacking industrial targets, command and control centers, and political control assets based on consideration of smoke and dust creation? Should enemy targets be rated by these criteria, for example, and their priorities be reconsidered? Should some targets be placed in withhold categories to minimize collateral fires and dust?

The list in the Palomar report goes on and on about serious policy issues that should have been raised by the DOD study.

In reading the DOD report, I got the very distinct impression that, outside of the uncertainty aspects of the nuclear winter a last-minute effort was made to put something together to submit to the Congress.

It was not good enough, in my judgment. So, I am hopeful that these kinds of questions will be asked. They have to be asked.

I am delighted that we will have the kinds of experts, such as Mr. Perle and Dr. Sagan, to testify to the committee.

[The prepared statement of Senator Cohen follows:]

Prepared Statement of Senator William S. Cohen

I would like to express my thanks to Dr. Sagan and Mr. Perle for joining us today, and I would especially like to thank the Chairman for agreeing to hold these hearings on the effects of nuclear war. His strong personal interest in this matter has helped to ensure that it receives the attention it deserves.

In their daily work at the Pentagon and elsewhere, our military planners make factual evaluations of how many nuclear weapons we should have, how powerful those weapons should be, and toward which targets they should be aimed. Similarly thorough evaluations of Soviet nuclear capabilities are continuously updated and revised.

The results are presented to decision-makers and factored into U.S. military planning. We on this committee receive numerous briefings and engage in important interchange with the administration on these matters.

In the course of these deliberations, we are presented with fact-filled charts, graphs and papers which tell us why our nation may need more of this, better of that. I do not suggest that these projections and proposals are wrong. Nor do I suggest that we should abruptly alter our course. The threat from the Soviet Union is quite real and growing and must be squarely faced.

But there is a dimension missing from our dialogue—the human factor. The neat calculations of CEPs and hard target kill capabilities, the jargon of first-strike counterforce targeting strategies pass rather glibly over the actual horror that both of our nations are capable of producing. Yesterday we were told that an exchange of 10,000 to 12,000 warheads could produce casualties ranging from several hundred million to several billion, depending on the season and other factors. Temperatures might drop significantly for several weeks to several months.

At the very least, we were told, there would be a significant disruption of the infrastructures of society, of commerce and agriculture. Mr. Chairman, I recall a few years ago during an interruption of oil supplies that people were shot while sitting in gas lines. People were burned to death while using vacuum cleaners to siphon gasoline from others' cars.

I don't believe anyone disputes that a large-scale nuclear war would be a catastrophe unprecedented in human history. But these recent scientific speculations present a prospect heretofore not seriously considered. In the worst case, a large-scale nuclear war could conceivably end human history, and even a "limited" nuclear war could conceivably have catastrophic effects on climate and agriculture extending well beyond the U.S. and the U.S.S.R. I am persuaded by Dr. Harwell's statement that more people would die of starvation than from the actual nuclear bursts.

There is a tendency to cavalierly dismiss the theory of nuclear winter as left-wing propaganda that serves the interest of the Soviet Union. Deterrence will prevent nuclear winter, if there is such a thing as nuclear winter, we are told. But I believe it is imperative for us to ask: What are the consequences should deterrence fail? What are the policy implications for our conventional assumptions and strategic plans?

A year and a half ago this committee adopted an amendment to the FY-85 Defense Authorization Act directing the Secretary of Defense to undertake an assessment of the nuclear winter theory and its potential policy implications. This stemmed from a concern that our military establishment might not be giving the nuclear winter research the attention that was appropriate. This concern was shared by some in the military. The Chief of Naval Operations' Deputy Director for Strategic and Theater Nuclear Warfare stated, in a November 1983, memo: "Unfortunately, there is very little likelihood of a serious examination of the broad policy implications being done by anyone knowledgeable in the Office of the Secretary of Defense or the Joint Chiefs of Staff."

The Defense Department submitted its report in March of this year. I must be frank in stating that, in reviewing the DOD report, I was quite disappointed because it did not adequately address the issues at hand, in particular the potential policy implications of the nuclear winter hypothesis.

That is why I believe this week's hearings are especially important. Hopefully, the discussions we are having will highlight some of the questions which need to be seriously addressed so that next year's DOD report will be a constructive addition to the dialogue on this important matter.

Mr. Chairman, Albert Einstein once said that "the unleashed power of the atom has changed everything in the world except our way of thinking." Many people would prefer not to think about the consequences of nuclear war; the prospect is simply too horrible. But if we are to deal prudently and wisely with this matter, we must know as precisely as possible what the effects of these weapons would be and how those effects should shape our policy. Therefore, I am quite pleased that you have called these hearings.

Chairman **Goldwater**. Thank you very much, Senator.

Doctor Sagan, we welcome you. You may proceed in any way you care.

STATEMENT OF CARL SAGAN, AUTHOR AND SCIENTIST

Mr. **Sagan**. Thank you very much, Senator Goldwater, Senator Nunn, Senator Cohen.

I am very happy to be here. I am told these are the first hearings on long-term consequences of nuclear war that have ever been held before the Senate Armed Services Committee. In any case, I quite agree that this is an extremely important issue which ought to be carefully considered.

The direct consequences of nuclear war are reasonably well known, although there are a spate of new findings which suggest that the prompt consequences of nuclear war might be considerably more serious than had been imagined previously.

For example, at the National Academy of Sciences just 2 weeks ago, the weekend of September 20–22, there was an extremely interesting meeting sponsored by the Institute of Medicine in which a range of new results came out—the suggestion, for example, that the amount of radiation necessary to kill a human being may have been overestimated by a factor of two.

Or, to take another example, a very interesting Brown University Medical School study suggesting that in realistic radiation conditions of nuclear war that the T-cells that are responsible for the human immune system would be killed and the net result would be to make a very large increase in the vulnerability to disease of people who received those doses—which are nowhere near as large as what it takes to kill a person. And the researchers there described this as a global case of the acquired immune deficiency syndrome [AIDS].

Here we are talking about the long-term consequences. The direct consequences have been variously estimated in a full nuclear exchange as killing between a few hundred million and perhaps as many as 2.2 billion, the latter an estimate of the World Health Organization.

The long-term consequences I am talking about you heard about yesterday and I will not spend more than a couple of sentences reminding you what the essential idea is.

This for me came out of something as far removed from nuclear war as imagineable, namely, studies of dust storms on the planet Mars from the U.S. spacecraft Mariner 9 in 1971. We found that the fine dust in the Martian atmosphere in the large dust storms had darkened and cooled the surface. It took us, I am sorry to say, many years before we realized that we had the ability to calculate what the climatic consequences would be for the Earth in the post-nuclear war environment.

Dust from high yield ground bursts and smoke from ground and air bursts, especially over cities, produce a pall of fine particles which spreads first in longitude and then in latitude, cooling and darkening the land surface beneath, especially far from coastlines.

The original TTAPS study treated a wide range of cases. We have now calculated almost 50 different cases for a diversity of nuclear war scenarios and a wide range of variation of those parameters which are known only imperfectly.

One of the consequences is that there is major change in the atmospheric structure of the Earth, which works to keep fine particles which are put up there up there much longer. Recent research at Los Alamos National Laboratory confirms that if you put thick palls of smoke up in the atmosphere, the heating of the sun will loft the smoke to still higher altitudes.

The higher the altitude these particles go, the more immune they are to scavenging, the less likely they are to be rained out or to fall out. A range of three-dimensional calculations now show that the effects are by no means limited to the northern midlatitude target zone, that the fine particles are carried over the Equator into the Southern Hemisphere.

There has now been a variety of studies, some of them carried out with initially very skeptical attitudes, by national and international scientific organizations. The National Academy of Sciences concluded that nuclear winter was "a clear possibility."

An interesting report of the Royal Society of Canada stated:

"We conclude that the nuclear winter hypothesis does indeed modify the global strategic position."

Before that they said "The climatic impact of the smoke pall is now shown to be probably capable of damaging crops and vegetation over a vastly greater area, perhaps the entire planet."

There is a most interesting recent study by the International Council of Scientific Unions, which was a 2½ year effort by several hundred scientists of several dozen nations. I will just read the two concluding paragraphs from that study. They say:

> Whatever the uncertainties, there can be no doubt that there is a considerable probability that a major nuclear war could gravely disrupt the global environment and world society.
>
> As representatives of the world scientific community drawn together in this study, we conclude that many of the serious global environmental effects are sufficiently probable to require widespread concern. Because of the possibility of a tragedy of an unprecedented dimension, any disposition to minimize or ignore the widespread environmental effects of a nuclear war would be a fundamental disservice to the future of global civilization.

I believe what the committee would like to stress today are the implications of the policy of nuclear winter and as the two preceding quotes show, it is widely thought that there are such implications for policy. Apparently this conclusion is shared by the administration.

In the September 19 issue of the British scientific journal, "Nature", an internal State Department memorandum, to the Secretary of State, dated August 16, 1984, is quoted:

> The implications for United States policy of the nuclear winter theory as it is being argued by Turco, Toon, Ackerman, Pollack and Sagan could be profound if the Administration's policy studies agree with Turco *et al.'s* conclusions and/or if by default congressional and public attitudes are molded by those results.

Let me briefly list a few consequences that seem to me possible or probable from a nuclear winter.

One has to do with nuclear warfighting itself. If there is a thick pall of fine smoke just over the northern mid latitude target zone or, more likely, larger areas, I imagine this would have some implications for surveillance satellites, for launch detection, for damage assessment from satellite altitudes, for aircraft and missile performance in an environment which is loaded with fine particles.

There are clearly a wide range of possible implications for strategy and doctrine, but I mention these as apparently clearcut and straightforward consequences which surely ought to be treated by the American military establishment.

To give an example of a very major departure from conventional wisdom which may be implied by nuclear winter, consider the issue of first strike. My understanding is that a significant amount of the escalation of the arms race as well as the development and deployment of specific weapon systems is geared to a concern on each side that the other side will make a disabling first strike on land-based targets.

The TTAPS study suggests that even a pure counterforce first strike, that is, in which no cities are targets, only missile silos are attacked, could still, through the fine dust and subsidiary burning of vegetation and other burnable materials nearby, could still produce a significant nuclear winter. In a more realistic exchange involving a first strike there would be more burning, especially of cities and, therefore, still larger nuclear winter effects.

So, let us consider two nations, A and B, and let us imagine that nation A makes a major first strike on nation B and that nation B, for whatever reason, does not retaliate. What happens?

It now appears that the pall of fine particles rises over the attacked nation B, is carried by the prevailing winds, circulates in something like 10 days halfway around the planet and produces a nuclear winter, among other places, in the attacker nation A.

This is an extremely expensive and elaborate way to commit national suicide. Therefore, if this is (1) true, and (2), recognized on both sides, the knowledge of nuclear winter itself would provide some deterrence against such a first strike.

Another area where there seems to be policy implications of nuclear winter is the relations between the United States, the Soviet Union and other nations. It is sometimes said, I hear it occasionally, both from Americans and from Russians, that what is new about nuclear winter? We always knew that everbody would die anyway; this is just increasing the likelihood.

But the "everybody" that is meant in those remarks is everybody in the United States and the Soviet Union. Of course, that is an exaggeration, not everybody in those two countries would die from prompt effects. But people in other countries, people far removed from the northern midlatitude target zones are threatened, even if no nuclear weapons fall in their territory whatever.

It now appears possible that a nation like Brazil or Indonesia or Nigeria might collapse entirely from a nuclear war restricted to northern midlatitude, and as a result, a very interesting number of other nations are now speaking out because of their concern about the consequences for them. Many of them may have once thought they could sit out a nuclear war with rather small devastation. That no longer appears to be the case.

As you heard yesterday from Dr. Harwell, the agricultural implications of nuclear winter are themselves so severe that massive global starvation is a very likely consequence, especially because of the reliance of many other nations on the northern midlatitude countries, especially the United States, for direct supplies of food, but also for fertilizers and insecticides and fossil fuels for tractors and the rest.

The collapse of the United States and the Soviet Union would have profound implications for those other nations.

Senator NUNN. Could I interrupt for one point of clarification here?

Chairman GOLDWATER. Yes.

Mr. SAGAN. Please.

Senator NUNN. Are all these results you cite from an all-out attack on those military targets and cities?

You started off by saying attack by nation A against nation B. Strictly on a counterforce basis, strictly against silos, not cities, followed by no retaliation whatsoever by nation B, still would have profound effect?

Mr. SAGAN. Yes, but less profound.

Senator NUNN. Then you went on and gave the other assaults. I am having trouble understanding whether you are talking about the same scenarios.

Mr. SAGAN. I essentially wasn't.

Senator NUNN. You were going to an all-out attack?

Mr. SAGAN. Yes. Let me give a feeling for the numbers and you can judge, yourself.

The kinds of numbers that seem to be possible in a pure counterforce first strike are temperature declines of many degrees, maybe even up to 10 degrees. Temperature declines in a major exchange, a central exchange between the two countries involving hundreds of megatons in city attacks, something like that, might be significantly more than that in a summer war, 20, maybe 30 degrees centrigrade.

We do not very much know how much agricultural failure for how much temperature decline, but to give you a calibration of that, the Royal Society of Canada report and International Council of Scientific Union report both stress that a 4 degree temperature decline would be enough to wipe out all grain production in Canada.

Many nations in other parts of the world may have thought they could sit out a nuclear war between the United States and the Soviet Union. That now seems to be untenable. Even countries that are not on the edge of starvation, that provide more than minimal nutrition for their citizens are at risk.

For example, Japan. Japan imports more than half of its food supply. So, in the unlikely case that Japan were utterly untouched in a central exchange between the United States and the Soviet Union, nevertheless more than half of the food imports of Japan would be unavailable and massive starvation would occur there.

Another implication surely has to do with civil defense and shelters because the magnitude and the duration of the nuclear winter effect is very inconsistent with at least the kinds of shelter and internal emigration programs that we are familiar with.

The standard calculations suggest that it may take as much as a year for the climate to return to its ambient values after a central exchange, and there are some reasons to think it might be significantly longer than that.

One other possible implication clearly has to do with the Strategic Defense Initiative. As Senator Cohen mentioned, the Department of Defense response to the Congress on what the policy implications of a nuclear winter would be was restricted exclusively to SDI. It was argued that the only policy implication of nuclear winter is that it strengthened the case for the strategic defense initiative.

I would therefore like to say a word about that, if I may.

The most optimistic numbers by technically capable adherents of the administration's position are that in some decades we might have a strategic defense system that is something approaching 90 percent effective. That is, something like like 90 percent of incoming Soviet warheads could be destroyed and would not detonate on or over American territory.

I have here schematic artwork done by John Lomberg. A Soviet attack of many thousands of warheads, perhaps as much as 10,000 warheads, with 90 percent of those warheads destroyed leaves 10 percent or something approaching 1,000 nuclear weapons untouched. But 1,000 nuclear weapons landing on the United States is sufficient surely to destroy the United States as a functioning entity.

Therefore, in terms of protection of civilian populations, but also in terms of preventing nuclear winter, it is hard for me to see how SDI helps.

In addition, a plausible Soviet response to SDI—there are many of them—is to increase the number of their offensive weapons. They would presumably be cautious and so increase the number of their offensive weapons more than they believed is the likely capability of the American SDI to shoot down their offensive weapons.

The net result might be that the world is significantly more at risk from the likely Soviet response to SDI than if SDI had never been deployed.

I have two final remarks. One has to do with worst case scenarios.

It is sometimes said in criticism of the nuclear winter that the nuclear winter effects occur only in the worst case. As I tried to indicate, that simply is not true. It now looks that much less than the full strategic arsenals, perhaps 1 percent of the arsenals, would be sufficient to bring about nuclear winter. But this raises an important question.

The reason that the worst case analyses are so common in military thinking, as I understand, is because you cannot risk relying on the presumed intentions of the potential adversary. You have to plan for the worst case and be ready for that. That is considered the only prudent approach. But the worst case of nuclear winter seems to me to carry with it exactly the same argument.

From this I conclude that there are vastly too many nuclear weapons in the world, that it is insufficient to say that it is unlikely that they will all be used, that both sides would exercise restraint, that the safeguards are adequate.

It seems to me that the only truly safe circumstances is to make sure that there are so few strategic nuclear weapons that nuclear winter could not be triggered, no matter what—even if everyone went crazy. Nobody knows just what number that is, but it does appear to be sufficient to represent a very powerful retaliatory capability and, therefore, there is at least the prospect that massive reductions in nuclear arsenals carried out bilaterally and verifiably could bring the arsenals below the threshold for triggering nuclear winter and still preserve, if we so wish, an invulnerable retaliatory capability.

I would like to conclude by reading a few sentences from a petition that I drafted that has now been signed by just short of 100 Nobel laureates worldwide:

> Human technology is now able to destroy our global civilization and perhaps our species as well. The lives of all those who inhabit the earth today and of all generations yet to come are in jeopardy. Nations and peoples, even those far removed from the probable nuclear war target zone, now face unprecedented devastation. The danger of nuclear war cuts across religious, economic, social and ideological boundaries. . . .
>
> Whatever our aspirations, prospects and ambitions for the future, whatever our hopes for our children and their children, all are now imperiled by the prospect of nuclear war. We share a small planet and an intricate and delicate life support system. In the name of our common humanity and on behalf of all the human beings who have been, who are and who are yet to be, we urge the peoples and the nations of the earth to reverse the nuclear arms race and to speak for our species and our planet.

Thank you very much.

Chairman **Goldwater**. Thank you very much, Doctor.

Now we will have the privilege of hearing from Mr. Perle, Assistant Secretary of Defense for International Security Policy, and who is responsible for nuclear policy matters in the Department of Defense.

Welcome. Nice to have you back.

STATEMENT OF HON. RICHARD N. PERLE, ASSISTANT SECRETARY OF DEFENSE (INTERNATIONAL SECURITY POLICY)

Mr. **Perle**. Thank you, Mr. Chairman.

I have only a very brief opening statement. It may be the shortest opening statement that was ever delivered to this committee.

Mr. Chairman, those of us who are responsible for developing and managing American strategic policy are indebted to the community of scientists who have alerted us to the danger that a nuclear war could lead to profoundly destructive climatic change. But while the discovery of nuclear winter may have deepened the apprehensions of the scientists who discovered it and their audience, its contribution to the wisdom of our thinking about war and peace is far from clear.

The first principle of our strategic policy is to prevent a nuclear war; and the means by which we have sought to accomplish this is the maintenance of a stable balance of nuclear forces.

This was the policy adopted by administrations before this one and I suspect it will be the policy of those that come after. It preceded—and I expect it will also follow—the discovery of nuclear winter.

The realization that a nuclear war could lead to catastrophic climatic change has caused some people to question whether the United States is doing all it can to avoid such a war. It has caused others to conclude that we ought to abandon our policy of deterrence—as though a policy aimed at preventing a nuclear war without a nuclear winter must inevitably differ from a policy aimed at preventing a nuclear war that might carry a nuclear winter in its aftermath.

I must say that among the several reactions to the discovery of nuclear winter, the one I have trouble understanding is a mindless embrace of the notion that we should freeze our nuclear forces, abandon research on strategic defenses and reaffirm the policy of attacking urban centers in the Soviet Union by proclaiming the tonic effect of mutual assured destruction.

Freezing our nuclear forces—and presumably Soviet forces as well—at the levels that now obtain—levels that Dr. Sagan and others have said would comfortably ignite a nuclear winter—would hardly seem the answer to our prayers. Derisively dismissing the development of strategic defenses—I think that looney tunes is Dr. Sagan's clinical scientific judgment about its feasibility—when faced with the awesome consequences of unintercepted weapons landing on the Earth's surface strikes me as wee bit glib. And celebrating the virtues of a strategy of bombing cities when it is the burning of cities that causes nuclear winter makes one wonder whether the cure is not being confused with the disease.

I believe that the danger of a nuclear winter should cause us to redouble our efforts to bring about significant reductions in the number and destructive capacity of nuclear weapons. It should support the refinement of our strategic plans in the direction of weapons with reduced yield and greater accuracy aimed, not at cities, but at military forces. It should encourage a reexamination of the doctrine of mutual assured destruction and a greatly enhanced interest in strategic defense.

These are the policies of this administration. They are policies based on an appreciation of the catastrophic consequences of nuclear war that has been reinforced by the discovery of nuclear winter.

Thank you very much.

Chairman GOLDWATER. Senator Nunn?

Senator NUNN. Mr. Chairman, is 10 minutes the understanding?

Chairman GOLDWATER. You go ahead.

Senator NUNN. I want to ask a couple of questions for each witness.

Dr. Sagan, without quibbling about SDI and whether perfect defense is 90 percent or 91 percent or 92 percent, generally let me ask you about your scenario. You talk about 10,000 warheads in the inventory. Let us say there is 90-percent hypothetical defense against those in some decades ahead or years ahead if SDI is successful.

You have postulated 1,000 weapons getting through, being the 10 percent, and that nuclear winter would result from that; is that correct?

Dr. SAGAN. That is essentially the kind of example I was giving.

Senator NUNN. Are you assuming those salvos are aimed at cities or at military targets?

Dr. SAGAN. I was imagining a distribution. The reason for that distribution is that, as many experts have testified, there is an awkward proximity and colocation of strategic targets and places where burnable materials exist, including cities.

I am thinking, for example, about secondary airfields for the dispersion of strategic bombers in time of crisis—many of which, as the Cuban missile crisis clearly showed, are in or near cities. I am thinking about places like Bangor, ME, Charleston, SC, and other places which are——

Senator COHEN. Atlanta?

Dr. SAGAN [continuing]. Ports for nuclear submarines, and if we add missile silos, weapons depots, command and control facilities and the like, then the consequences I am talking about follow.

Senator NUNN. Mr. Perle, you mentioned here on page 2, "It should encourage a reexamination of the doctrine of mutual assured destruction and a greatly enhanced interest in strategic defense." A couple questions on that.

Are you saying this administration now has a policy of mutual assured destruction?

Mr. PERLE. I think it has been our policy, American policy, for some time, Senator, to threaten unacceptable damage in response to an attack upon the United States and that doctrine has come to be known as the doctrine of mutual assured destruction.

Senator NUNN. Are you saying that is the administration's policy?

Mr. PERLE. It is an element of American policy. That is not the whole of our policy.

Senator NUNN. That is not what we described our policy as being in the last two or three administrations beginning in the 1970's. In fact, there was a determined effort to move away from that kind of policy to have more accurate weapons, to have more target options, to not have something after cities, and so forth.

If indeed our policy is mutual assured destruction, as you have said, what is the purpose of more accurate weapons?

Mr. PERLE. I don't believe our policy should be based wholly on the capacity to destroy the cities of the Soviet Union. That is the heart of the dispute, I believe, between those of us who think we should have more discriminating weapons aimed at military targets rather than a minimum, and those minimums are usually very large, a minimum number of weapons aimed at cities of the Soviet Union.

The irony of this issue in this debate is that it is scientists' positions who have for a very, very long time now been the principal proponents of offensive forces only and offensive forces aimed at the civilian population of the other side.

Senator NUNN. I have conversed with the last several Secretaries of Defense and I have not heard any of them describe our present posture for the last decade as being mutual assured destruction.

The things I keep getting frustrated about, and you have confirmed my fears today, is that we have now seen this administration come back and describe our policy of mutual assured destruction as a way of saying that is the only choice, either mutual assured destruction or SDI.

It is a sales tool, but it is a considerable backing up of 10 years of evolutionary doctrine and getting away from the only option of hitting cities and making that as a last resort and moving to accurate weapons, smaller yields, that started back with Secretary Schlesinger as Secretary of Defense.

It seems to me it is totally confusing the American public in using words like mutual assured destruction as a sales tool for SDI. I happen to support the research in SDI and did before the President made his speech.

I think you are really not contributing to a clear understanding when this is continually done. It has all been done in this adminis-

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I think you are really not contributing to a clear understanding when this is continually done. It has all been done in this administration and, in effect, is a reversal of a solid decade of effort by Republican and Democratic administrations and very competent Secretaries of Defense to move off that kind of option. But you are here saying today that still is our policy.

Mr. PERLE. No, you misunderstand me. That is not the case.

Senator NUNN. Let us see what you did say.

Mr. PERLE. It is not the case that our only option is to attack the cities in the Soviet Union. We have other options. Some of those options were first developed in connection with the studies to which you referred and which I would very much support.

There was an argument about whether we should continue down that path, as you well know, and this administration is very much in favor of continuing down the path of enlarging the number of options available to the President, incorporating in our forces weapons that are capable of greater discrimination, fewer collateral effects, and the like, and in attempting to move in this direction the argument that is most frequently invoked against us is the argument that we are moving to what is characterized as a warfighting strategy and that is an argument invoked most often by those who are most alarmed by nuclear winter.

That was the point of the remark I was making.

Senator NUNN. I think you are really backing up several years in debate. That was the argument made several years ago. I have not heard arguments made against more accurate weapons on the Hill for a long, long time.

We have people in favor of the small missile. We have people mostly that are opposing the MX, not because of the accuracy of the missile, but because of the basing mode. We are moving toward the D-5 missile in the Trident submarine on which I have heard no objection from anyone.

It seems to me in an effort to sell SDI, you are using a very questionable tactic to get the American people to believe that 10 years of solid effort to try to move away from mutual assured destruction has not been productive. I think it is an unfortunate way of trying to sell a program.

Mr. PERLE. I did not come here to sell SDI. I think if you ask Dr. Sagan how he feels about the D-5 and the other weapons you referred to, you will find he is not enamored of the movement in that direction.

Senator NUNN. What his position is on that is irrelevant. It is a question of whether we have a policy of mutual assured destruction in this country today. You are saying we still do. I thought we had moved off that a long time ago.

Mr. PERLE. I am trying to be clear it is not our only option. We do not target civilians as such. We have been moving as effectively as we can away from that, but it is still the case that we depend in the final analysis, given the nature of our forces and the nature of the Soviet forces, on the threat to retaliate and deliver an unacceptable retaliatory blow against the Soviet Union.

Senator NUNN. That is not the same as mutual assured destruction. Mutual assured destruction is going after cities and making those priority targets.

What you have just described as unacceptable damage relates to military targets using cities only as an absolute total last resort.

We are moving steadily away from that. In fact, when we get the D-5, the combination, the MX and the small missile, we are moving very, very substantially away from that.

Mr. **Perle**. There is no disagreement between us on that, neither the fact of what is happening nor the desirability of it.

I think you will find among those who concern themselves with nuclear winter the view that you have expressed and that I share is not shared by them.

Senator **Nunn**. That may be true. I hope we continue. We have worked toward getting a clear understanding of our policy. It is not just your statement. I have seen it in the statement of the Secretary of Defense. I have seen it in statements coming from the White House posturing two choices we have, either SDI or continuation of the immoral policy of mutual assured destruction.

That is a choice between two things that are not necessarily only two choices. As you have just said, we have moved substantially away from mutual assured destruction. It is the final resort and our policy for a number of years through several administrations has not been a policy of mutual assured destruction.

Mr. Chairman, my time is up.

Chairman **Goldwater**. Senator Cohen?

Senator **Cohen**. Dr. Sagan, one of the criticisms we have heard is that the original TTAPS study greatly exaggerated the potential consequences.

Do you agree that the conclusions you have reached in that study were greatly exaggerated?

And the second question would be what have you learned since 1983 with continued research in this field?

Dr. **Sagan**. That claim has been made, but if you look at all the recent studies, the work at the National Center for Atmospheric Research, for example, the work at Los Alamos National Laboratory, even the work at Livermore National Laboratory, you will find that temperature declines of 10 to 40 degrees occur in all of those models under certain circumstances, even short of a full exchange.

That is exactly the temperature range that we predicted in the original TTAPS study. I think it is absolutely straightforward that there is no significant disagreement and that fact is widely recognized.

For example, an editorial in the magazine Nature, which has had an extremely skeptical editorial policy on nuclear winter, about the most recent Scope report by the International Council of Scientific Union says:

"What Scope says about nuclear winter does not differ qualitatively or in other significant ways from the earlier accounts of nuclear winter," and they then cite TTAPS.

We have learned much from studies since 1983. The TTAPS results were one dimensional calculations in which the global circulation of the fine debris produced in a nuclear winter was only discussed in a qualitative or at best semiquantitative manner.

Now, there are quite sophisticated three-dimensional models which track the global distribution of smoke and dust. One very important recent finding I alluded to earlier is that the smoke when heated by the Sun is lifted. Hot clouds tend to expand.

The net result of this is not only to spread the particles over a much larger geographical area, but to keep them up in the atmosphere for considerably longer than had been imagined earlier.

I should say that there are a number of significant uncertainties still with us and some probably will always be with us. This is not a problem amenable to experimental verification, at least not more than once.

One of the main uncertainties has to do with duration. There are a number of feedback effects that have not been properly taken into account yet. It is at least conceivable that when they are properly taken into account the net result will be that nuclear winter effects will last considerably longer than the few months to a year or two which is now generally accepted.

Senator **Cohen**. Let me turn to an issue raised, I think, by Mr. Perle. The position of the administration is we want substantial reduction in the numbers of nuclear weapons, we have been unable to get them and that the SDI Program has, in fact, been responsible for bringing the Soviet leadership back to the bargaining table in Geneva.

Assuming you are correct that an SDI Program at the most optimal level would be only 90 percent effective, 90 percent effective as a deterrent is better than zero-percent effective as a deterrent factor.

Dr. **Sagan**. Permit me to give you an analogy. We are talking about a shield that is 90 percent effective. There are other kinds of shields in human affairs.

Imagine a contraceptive shield which is 90 percent effective, which lets through 10 percent of 200 million sperm cells. Does that help or hurt? Might it lead to a kind of false confidence that everything is now safe? Would it, in fact, be desirable to have a shield of 90 percent impermeability?

The Soviets have open to them a number of options to make a 90-percent impermeable shield essentially useless. One is massive increases in the Soviet arsenal of offensive weapons which requires a technology which is now well in hand as opposed to SDI which requires a technology which is dubious at best.

The Soviets can underfly with cruise missiles and aircraft and bombs delivered by motorboats and light aircraft. I point out that illegal cargoes of proscribed materials arrive daily in the United States that are about the heft, if not the mass, of a nuclear weapon.

The Soviets have the option of decoys and penetration aids so that we must imagine not just 10,000 nuclear weapons or something like that, we must imagine them immersed in a threat cloud of maybe hundreds of thousands of decoys and penetration aids.

So, for all these reasons I believe that SDI is an example of what has been called The Fallacy of the Last Move, the idea that only more technological advance and then we are safe.

The entire history of the arms race has shown that every such purported last technological advance is matched or countered by the Soviets and then we ratchet up the escalation ladder one more step.

Take a look at MIRVing which many people considered to have increased the risk of both nations and certainly is much more destablizing than when there was only a single warhead per missile. That is exactly the same kind of situation; it was argued that the United States had an opportunity to make a decisive technological advantage.

So, that is at least a partial answer, Senator Cohen, to my concerns about SDI, to say nothing about the immense cost and the possibility that it will be perceived by the Soviets as a component of an American plan for a first strike and, therefore, leads to a Soviet preemptive strike that is to bring about the nuclear war which it is supposed to prevent.

Senator COHEN. Mr. Perle, I would like to have you explain something for me to clarify the issue.

I know that Dr. Sagan has just mentioned that one alternative to the Soviets would be to simply try to overwhelm the defenses. The report that DOD filed indicates a conclusion just the opposite, that they would be less likely to in fact initiate a first strike.

Last year there was a report that members of this committee heard, it was erroneous it turned out, but the report came that the Soviets had developed a look down/shoot down capability which they used against a cruise missile they had launched.

My question then was, and now is, assuming that the Soviets do have a look down/shoot down capability for cruise missiles: Would your recommendation be that the military planner cancel the cruise missile program?

I know the Air Force is sitting behind you. We will call on him in a moment to answer that.

Mr. PERLE. I think it is the case, Senator, with respect to weapons on both sides, offensive and defensive, that there is an interaction between them and one does not scratch one's offense because there is a partial defense with respect to it.

I am not sure how that relates to the earlier observation. Without taking Professor Sagan's analogy any further, it does seem to me that if the best you can do is 90 percent effective, that is better than zero effective.

If you can discourage a first strike by so greatly increasing the likelihood that the first strike would fail, even if you can't prevent it 100 percent, that is an enormous contribution to deterrence.

I think that the professor misses the point about strategic defense. It is not necessary to have a leak-proof defense in order to diminish the effectiveness of the first strike and thereby to deter that first strike, although I must say if you hold to Professor Sagan's view that a strike will lead to a nuclear winter, I think one can go away quite confident that the world is safe and secure since no one in his right mind would take an action that would bring about a nuclear winter.

Senator COHEN. Let me respond briefly. You do not see the connection between the question on SDI and the look down/shoot down capability. This is the question I am trying to resolve in my own mind.

The DOD report categorically dismisses the notion that the Soviets would resort to an increase in offensive weapons.

What I am suggesting is that our reaction to a disclosure that the Soviets have developed a defensive mechanism against cruise missiles would not be to reduce the number of cruise missiles or cancel the cruise missile; it would be to build a better cruise missile or build more of them or make them stealthy, or in some other way able to penetrate those defenses.

There is an intellectual connection between the notion that if we could erect a defense, we will not discourage the use of that system, but we may, in fact, proliferate that system.

Mr. **Perle**. It depends very much on the purpose of the system and on the details of the situation you are talking about.

In the case of a strategic defense, the sort of strategic defense in which we are most interested and the approach to strategic defense that we now think is most probably promising, which is the interception of Soviet missiles in the boost phase, if successful, would impose such enormous penalties that the Soviets might well conclude that it was not plausible within reasonable budgets to add additional offensive weapons to overwhelm that defense.

There are lots of weapons no longer manufactured because they are no longer effective. I don't see why that is not the applicable analogy in a case like this.

Senator **Cohen**. Thank you.

Chairman **Goldwater**. Senator Hart?

Senator **Hart**. Dr. Sagan, is it possible for this Nation to maintain an effective deterrent and reduce or eliminate the danger of nuclear winter, and if so, how do we do that?

Dr. **Sagan**. Senator Hart, I think that the answer is something like this.

Since a tiny fraction of the existing strategic arsenal of the United States and the Soviet Union are adequate as far as we can tell to bring about nuclear winter, you could have massive cuts—for example, a factor of two cuts is being talked about in some circles these days—in the strategic arsenals and in no significant way diminish the capabilities of either side to bring about nuclear winter.

In fact, it appears that even the French and British and possibly even the Chinese strategic forces are adequate to bring about nuclear winter.

Authoritative commentary seems to hold that much of their forces, the French *force de frappe,* for example, is targeted mainly or even exclusively on Soviet cities. So, bringing about nuclear winter is not a problem restricted to the United States and the Soviet Union. It is a global problem.

But it is also clear that arsenals still smaller than appear to be required for nuclear winter can render unacceptable damage by either superpower on the other. To my mind the conclusion is that the long-term objective of arms reduction ought to be to bring the global arsenals below the threshold for nuclear winter while still maintaining, if we like, the capability for massive nuclear retaliation.

Senator **Hart**. Doctor, those of us who are not scientists practically worship the precision of science, the certitude of science. Yet, we come to a situation such as SDI and we see the scientific community experts, physicists, engineers, at wide variance over the practicability of a potential defensive system as outlined by the administration.

How do you account for this wide variance? I am sure it has nothing to do with the attractiveness of the research dollars.

How can scientists be so far apart on whether we ought to be pursuing this or not?

Dr. SAGAN. Scientists are human beings like everybody else. Scientists have political prejudices just like everybody else. This is not a situation like when will Halley's Comet come closest to the Sun in its forthcoming perihelion passage. That is a situation which requires essentially knowledge of newtonian physics and hardly anything else. It is a well-established area of science.

Here we have a hardly fleshed out a program or scheme which requires, as former Undersecretary of Defense DeLauer stressed, six or eight new technologies each of a cost and difficulty compared to the Manhattan project or the Apollo Program—to say nothing of the fact that there is a wide range of Soviet responses which are, I believe, inevitable if we were so foolish to go ahead and which would greatly complicate the task.

So, different people make different stress on the various points I have just made. I think that accounts for some of the variance of opinion. If you ignore the probable Soviet responses, SDI looks much easier.

This is not a simple scientific issue. There is not even a proposed Star Wars Program that you can look at and get our teeth into. What we are told is, well, we are looking into it and 20 or 30 years from now we will tell you what it is and then you can decide whether it is any good.

The trouble is that 20 or 30 years from now the national treasury will have been spent. The amount of deflection of intellectual resources into this and the amount of increased global tension will have done considerable damage, even terrible damage.

Senator HART. Mr. Perle, the President announced his discovery, whether it was, in fact, at the time his discovery, of the defense option in March 1983, as I recall. That is some 27 months into the first Reagan administration.

What was the administration's fundamental nuclear policy or doctrine before that date?

Mr. PERLE. I don't think that fundamental doctrine has changed. Let me stipulate that first. I think the Strategic Defense Initiative is an effort to determine whether it may be possible to develop and deploy defenses that would in the first instance at least strengthen deterrence and ultimately, depending on the results of that research, protect our people.

But our policy remains what it has been, not only in this administration, but in the post-war period, to deter attack on the United States and its allies by possessing adequate retaliatory forces at all levels from the conventional to the strategic nuclear level. That was not changed by the decision to explore strategic defenses.

The Soviets are busy exploring strategic defenses of their own and I think it is fair to say in the absence of an American program, we will wake up one day and discover the Soviets alone have accomplished the fundamental research and development necessary to produce strategic nuclear defense.

Senator HART. Why didn't the administration discover that in January 1981? What happened during those 2 years?

Mr. **Perle**. I don't know that there was any event of singular significance during that period. I think what happened was that research in the area of strategic defense pretty much came to a halt in 1972 with the conclusion of the ABM Treaty.

Senator **Hart**. Mr. Perle, wait a minute.

Would you restate that answer?

Mr. **Perle**. I said research with respect to strategic defense pretty much came to a halt with the conclusion of the ABM Treaty in 1972.

There was a low level annual appropriation for research, principally funds appropriated to the Army for what was going on in Huntsville and a few scattered laboratories here and there, but it was not a very vigorous program and it was not a program that entailed the application of new technologies that emerged largely in the civil sector, to the task of strategic defense.

Senator **Hart**. We will have to disagree factually on that. I cannot account for 1972 to 1975. I do know from 1975 to 1983 or whenever the President made his speech that millions of dollars got spent in defensive technology. But go forward anyway.

Mr. **Perle**. In relation both to the overall R&D program and in relation to research and development on offensive forces it was relevant, in my judgment. Maintenance level would be a fair way to describe it.

But in 1983 with the development over a decade or so of civil technologies in a number of areas, data processing, sensors, and the like, with the discovery that the Soviets had a very sizable program underway and were probably making significant progress with, with the growth of Soviet offensive forces that we had hoped and some had believed would not take place following the treaty of 1972 and its associated limitations on offensive forces, the President came to the conclusion that we should make a much more vigorous research effort to establish the feasibility of SDI.

Frankly, I believe that had he not come to that conclusion, some other person would have.

Senator **Hart**. In effect, what he was doing was responding to the Soviet Union and to just the collection of, as you say, civil inventions or discoveries?

Mr. **Perle**. The evolution of civil technology that made possible approaches to SDI that were not possible a decade earlier.

For example, data processing, it is possible to imagine in very small packages the capability to perform literally billions of calculations per second and for the development of systems that would entail real time data processing possibly in space, the kind of miniaturization we have seen in the electronics industries in the last 10 years or so has been critical to a potential SDI breakthrough.

Senator **Hart**. I find it very difficult to quarrel with your original statement of what SDI was. It sounds to me like the statement made by Ambassador Nitze in a speech last spring in which he laid out the conditions for SDI if certain things proved feasible and if we determined we were able to link complicated technologies, then it was something worth going forward on.

That, however, as others have commented, is not the way the President talked about this, not the way Secretary Weinberger talked about it, not always the way you talk about it.

There are vast discrepancies in the way the administration described SDI to the American people and to the Congress. I think that is why you get vastly different responses to it from the American people and from the Congress because there is such a wild discrepancy between what it is and what it is supposed to be.

All I can tell you is that if the administration begins to particularize the description of what it is after here, it might be easier for people to respond to it one way or the other. I must say even in your case there are all kinds of descriptions of what this is and what it is intended to be and they are not totally consistent.

Mr. PERLE. The budget we send up is pretty specific.

Senator HART. The American people don't respond to budgets. They respond to administration rhetoric and that rhetoric is widely contradictory.

Thank you.

Chairman GOLDWATER. I might say that a major reason that I have called these hearings is first at the suggestion of Senator Cohen, but to call attention to the American people to this added factor that frankly, until a year ago, we didn't hear much about nuclear winter.

I don't believe for one minute that the addition of the threat of a so-called nuclear winter diminishes or ends the need for nuclear defense. As I say, we would like to get the American people better acquainted with what can happen.

I have to confess that the result of my interest in this, I told the Doctor, is after wonderful long discussions with Dr. Alvarez on the Nemesis theory, and I figure if it could happen 13 million years ago, it could also happen whenever we might happen to use nuclear weapons.

I do not see any new threat except the fact that there is that possibility of killing off a lot of people like the Nemesis theory killed off all the dinosaurs and I do not want to be one of those dinosaurs. That is one of the reasons for these hearings.

Mr. Perle, you are a formulator of policy in this area.

How do you deal with the uncertainty of the scientific data underlying the nuclear winter hypothesis?

Mr. PERLE. I think the first thing you do is recognize that the uncertainty is there. I was grateful to Senator Nunn for a question that caused Dr. Sagan to be precise about the conditions under which the scenario he was describing might take place.

I think it is important to be precise or as precise as we can. Too often there is a casual transfer of statements that we can make with confidence into areas where we can only speak with less confidence. It is almost certainly the case that a nuclear winter will result from a very large-scale nuclear exchange.

At the other end of the spectrum, that is, the small nuclear exchange and the point at which it might trigger nuclear winter, I think it is fair to say there is tremendous uncertainty. I do not think anyone is in a position to say that the British nuclear forces are by themselves sufficient to trigger a nuclear winter.

I am quite sure that one could not begin to make that judgment without knowing a lot more about the circumstances under which those weapons were used than we now know or could anticipate.

So, I think it is important to be precise and I think it is important for the public to recognize where science can make precise judgments and where it cannot. I do not want to find out where the dividing line is.

So, it seems to me, as I said in my statement, we need to redouble our efforts to maintain a strategic balance that will prevent a nuclear war.

Chairman **Goldwater**. I agree with you.

Mr. Perle, have you had any contracts with our allies that would give you the ability to assess what our friends and the Third World response to a nuclear winter hypothesis might be?

Have you had any reaction from other countries?

Mr. **Perle**. I recently attended a meeting that Dr. Sagan was also present at in Geneva where Dr. Sagan made a presentation on the subject. There were a great many people present from Third World countries who are understandably concerned that they might become victims in a war in which they were not directly involved as combatants.

Where I think they have had difficulty finding a response is in knowing what policy consequences flow from that realization. Too often they have joined the chorus of those seeking simple solutions like a nuclear freeze, which, if I understand Dr. Sagan, would freeze nuclear weapons at levels greatly in excess of what would cause nuclear winter and, therefore, would make literally no progress in diminishing the threat about which he and they are concerned.

So, they do not know how to respond to the threat, although they feel the threat. They are concerned and there is no question about that and they have a right to be concerned.

Chairman **Goldwater**. By the way, in the next round of questions if either one of you want to argue with the other relative to an answer, do not hesitate. I did not expect 100 percent agreement.

One question, Dr. Sagan.

In yesterday's testimony Dr. Gillespie provided the committee with his views regarding the heirarchy of possible effects of nuclear war along with their probabilities. His heirarchy ranged from well understood prompt effects to very low probability that the human race would become extinct.

Would you share your views on these possible effects and probabilities?

Dr. **Sagan**. It is very difficult to quantify these probabilities of how well we know things that have never been subject to experimental replication. Even the issue of what the prompt effects are, as the meeting of the Institute of Medicine of the National Academy 2 weeks ago illustrated dramatically, is subject to enormous change.

The possibility that the amount of radiation it takes to kill a human being might be half of the conventional widsom under realistic circumstances, a conclusion drawn from a careful study of the causes of the death of people in Hiroshima and Nagasaki, is simply astonishing to be discovered 40 years after Hiroshima and Nagasaki.

The fact that it took 37 years for nuclear winter to be discovered suggests that there may be many other effects, many other very serious effects, that have not yet been discovered. It raises the issue of what else we have overlooked.

I do not exclude myself from this complaint because we had the capability of calculating nuclear winter many years before we did and I wish we had had the vision to do it much earlier. I am very sorry that we did not.

But this sequence of events suggests that confident assertions that we understand the results of nuclear war may very well be mistaken.

For example, I understand—I may be mistaken, but I understand—that it is a requirement for the joint strategic target planning staff to prepare a document called "Consequences of Execution," which would advise the President or other national authority in the case of a nuclear war what the consequences of various courses of action would be.

An interesting question for me is this: Does this document include nuclear winter? What does it say about radiation effects? What does it say about intermediate time scale fallout? What does it say about pyrotoxins, the toxin smogs that now almost certainly appear to be produced in the burning of a modern city?

What does the "Consequences of Execution" document say about the depletion of the ozonosphere from the explosion of high-yield nuclear weapons? How carefully have these kinds of items been folded into the decision about whether or not to launch a nuclear war and if so, what kind of nuclear war?

Another aspect of this is the issue of research, research on nuclear winter and its implications for policy and what is quite properly called doctrine. Doctrine, as I understand it, in religion as in nuclear war policy, is something that you believe you would have trouble justifying to a skeptic.

The administration's effort to do research on nuclear winter is apparently restricted to $5.5 million, of which only $500,000 is administered by the National Science Foundation, the rest of it being Department of Defense and Department of Energy money and almost all of it going to Government laboratories.

Therefore, there is very little research on even the physician's end of this in the academic community. This seems to me a shamefully small amount of money, considering the seriousness of this problem.

Moreover, there is not a penny of this money that has been allocated to research on biology. At least this was true as of a couple months ago. The argument has been that until you thoroughly understand the atmospheric effects, you do not want to spend time studying the biology. That is a prescription for doing nothing in biology.

Beyond that there is the question of policy and doctrinal implications. Is there a serious study ongoing in the Government? Is there money for research outside the Government on policy and doctrinal implications? Why is it that there is such a sparse amount of money available for studying nuclear winter and its implications?

Chairman **Goldwater**. Sam?

Senator **Nunn**. I have a couple of lines here. Let me pursue one. I do not think we are going to solve and all agree on SDI today.

We might be able to recite that as a scientific certainty for purposes of this hearing, but taking Dr. Sagan's example of a 90 percent successful defense, hypothetically, using that as an assumption, it seems to me that the question of whether nuclear winter has an impact on the need for SDI—and I believe Mr. Perle said here that the nuclear winter hypothesis should enhance our interest in SDI or words to that effect—I don't have the exact words, again I favor a very vigorous SDI research program. But I think we are going to have to measure SDI by whether it enhances deterrence, as you mentioned a few minutes ago.

If it does, I think it is justifiable whether or not we believe in nuclear winter.

If it does not enhance deterrence, it seems to me nuclear winter would not affect that SDI Program one way or the other.

But just for the purposes of exploring that, assuming a 90-percent defense and assuming a nuclear winter effect that Dr. Sagan has predicted, Dr. Sagan, first a question to you:

How many cities have to be destroyed? How many cities have to be hit in order to produce a nuclear winter? Is there a threshold that you can state?

Dr. SAGAN. If I may spend 2 minutes on the answer.

In the Second World War nuclear weapons were exploded on two cities, and no nuclear winter followed.

There were also fire storms in places like Hamburg, Dresden, and Tokyo from conventional attacks and they did not produce anything like nuclear winter.

When we calculate whether they should have caused nuclear winter, we find they should not have. If I could draw a curve in the air, the magnitude of nuclear winter effects versus the number of cities, let us say, burned, the effect is zero for a few to a large number of cities, and then there is a kind of threshold amount of fine particles in the atmosphere which make a dramatic drop in the temperature.

We have calculated that the destruction of 100 city centers would be sufficient. It may well be that something significantly less—a few dozen city centers—would be sufficient.

Senator NUNN. Mr. Perle, do you agree with the 100 figure, or do you disagree with that? I am not asking you to verify it.

Do you disagree with that or have any reasons to disagree with it?

Mr. PERLE. I do not know if we know enough to get that precise about it.

Senator NUNN. Let me pursue SDI then.

Even if we had 100 percent SDI shield to prevent the United States from being hit with Soviet missiles, do we have any plans to defend the other cities of the world?

Mr. PERLE. You mean cities outside the United States?

Senator NUNN. Yes, for instance, Third World countries, Pacific countries, so forth.

Mr. PERLE. As I indicated earlier, the most promising area of research would lead to the capacity to intercept Soviet missiles in their boost phase before it is even possible to say what the target of those missiles is and it would, therefore, protect all cities.

Senator Nunn. In other words, if the Soviets were going to hit other cities, if we see them being launched, we could knock them out in the boost phase, no matter where they are aimed?

Mr. Perle. That is true for those missiles whose boosters burn long enough for sensors to detect the launch, but that would include the overwhelming majority of the Soviet ballistic missiles.

We have tended to think of SDI as a dome over the United States so that Soviet missiles launched against the United States would be prevented from penetrating that dome.

It seems to me rather more to the point to regard SDI, at least the boost phase element of the program, as a dome over the Soviet Union that would prevent those missiles from ever departing Soviet territory or the space above Soviet territory and in that sense our European allies and allies elsewhere would also be protected by it.

Senator Nunn. We have never felt we could get 100 percent at boost phase, have we?

Mr. Perle. Not in the boost phase, but the approach is a layered defense.

Senator Nunn. I understand that. That leads to my question.

What would prevent a perverse adversary such as the Soviet Union from hitting cities around the world as a response to United States SDI and knocking out 200 cities that were not defended?

I do not see how SDI is relevant to preventing nuclear winter. I do not think anybody postulates a defense that would prevent the Soviet Union, if they are perverse, from basically causing a nuclear winter by hitting other cities.

Mr. Perle. It sounds a bit unfair to strike a perfectly innocent party. The way to prevent nuclear winter is to prevent nuclear war. The way, in my judgment, to prevent nuclear war is to have an adequate deterrence.

That is where I part company with most of the community that has become concerned about nuclear winter because they are, as far as I can tell, deeply committed to mutual assured destruction.

I thought I understood Dr. Sagan a moment ago in response to Senator Hart to give a pretty good description of mutual assured destruction. That is, reduce the arsenals very substantially and still have enough to destroy the other side.

That, Senator, is my understanding of what we are trying to get away from.

Senator Nunn. You have described SDI as enhancing deterrence. If it enhances deterrence, that is the criterion we have to look at.

The President in his speech to the Press Club on March 29, 1985, said:

> We are not discussing the concept just to enhance deterrence, but rather a new kind of deterrence.

He goes on to say:

> At the same time through our strategic modernization program we must ensure our current weapons remain capable of performing their essential task until we reach that day when they may be replaced by a defensive system. It is elimination of nuclear weapons in the world that throws a lie in terms of the description of the program.

miss the point entirely. I cannot imagine the Soviets launching 10,000 nuclear weapons randomly at the United States which is what the chart depicts.

Senator **COHEN**. What is their rationale behind having 10,000 or 15,000?

Mr. **PERLE**. I am sorry to say I think the Soviets build nuclear weapons for two reasons.

One is they believe that there is a relationship between political influence and the size of their military forces, and so they do it for political reasons.

Second, they have constructed forces capable of attacking and destroying our ability to respond because I do not think they believe in mutual destruction, they believe they have quite a different strategy.

Senator **COHEN**. Your position is that they do not intend to use all these weapons, they are building them for political purposes only?

Mr. **PERLE**. No. I do not think they will fire 10,000 nuclear weapons randomly, which is what is implied by this piece of art. I do not exclude the possibility that if we were to permit the strategic balance to deteriorate to a degree, I am confident we won't, they would consider it a political bounty to have the capacity to attack and destroy much of our capacity to retaliate and that is what concerns me.

Dr. **SAGAN**. Secretary Perle argues no one in his "right mind" would do such and such. He says he "cannot imagine" that the Soviets would launch 10,000 warheads at the United States.

Contrast these remarks with his plea for accuracy earlier, his concern that remarks on this important subject only be made when you are really sure.

There is nothing random about the targeting that is intended on this chart. The argument was made when nuclear weapons were first MIRV'd that there would not be adequate targets for all the nuclear weapons now available, that there would not be targets for all nuclear weapons to be used, but that problem has been solved due to the enterprise of the targeteers.

On the issue of the freeze, it is very clear that if you wanted to reverse the nuclear arms race, you must stop it first. To say that any freeze of nuclear weapons production and development—as well as delivery systems—does not address the nuclear winter issue is most peculiar. Surely the present strategic arsenals are too large, but the way to reduce them is not to ever increase the number of weapons as the United States and Soviet Union together have been doing essentially monotonically since the invention of the weapons in 1945.

On Senator Nunn's question about Third World cities, it is an interesting question. How many cities are there on the planet Earth? How many potential targets?

If you define cities as having more than 100,000 inhabitants, there are something like 2,300 cities on the Earth.

With the joint strategic arsenals of the United States and the Soviet Union approaching 20,000, that means that every city on the planet could be destroyed and the two powers would have 15,000 strategic weapons left over. This then raises the very serious question of what are they all for—not just the Soviet side, as Senator Cohen mentioned, but the American side?

What are all those nuclear weapons good for? Is it prudent to have such immense arsenals of mass destruction on the planet? You have to be very sure of a wide range of possible circumstances to be confident that the worst will not happen.

I also want to remark on Senator Goldwater's comment about extinction. There is now a very widely accepted view, tracing directly from the discovery of Dr. Alvarez and his collaborators, that 65 million years ago there was an impact randomly with the Earth of an asteroid or comentary nucleus which sprayed large numbers of fine particles into the high atmosphere.

Perhaps nothing burned at all, just silicate particles that took a year or two to slowly settle out in the high atmosphere, and in that period of time the Earth was darkened and cooled sufficiently to produce massive biological extinctions. All the dinosaurs were wiped out certainly, but in addition, most of the species of life on Earth were rendered extinct at that time.

That is at what geologists call the Cretaceous-Tertiary boundary. There are claims, in dispute in the scientific community, that other mass extinctions have happened periodically or at least episodically by similar collisions with the Earth of objects from space.

It is important to remember that mass extinction is not merely hypothetical; it has happened. In fact, the vast bulk of all species that have ever lived on planet Earth are now extinct. The number of extinction events have destroyed something like half the species on the planet or more is many. It is five or six at least.

So, this is another reminder of the stakes that we are talking about. Where you are uncertain, you bias your results in the most cautious possible direction and that simply means that you reduce the numbers of nuclear weapons until the worst cannot happen.

I did not advocate mutual assured destruction in my answer to Senator Hart's question. I said you can reduce to a minimum deterrence and maintain the posture of mutual assured destruction if you like it.

If you do not like it, you can go down still further.

Thank you.

Chairman GOLDWATER. Senator Cohen?

Senator COHEN. Mr. Chairman, Senator Nunn asked how many cities must dance on the head of a nuclear warhead exchange. What strikes me about this discussion is that these concepts are all cast as polar extremes.

If anyone supports the theory or concept of nuclear winter, therefore, they ought to support the freeze, be it unilateral or mutual, they want to abandon research on SDI and they want to remove immoral targeting of cities.

I find that an extreme position to take. Most of the people, including myself, on this committee do support the theory, I think, of nuclear winter but do not support the freeze and have not supported the freeze, do support research on SDI and also see the wisdom of a dramatic reduction in offensive weapons, possibly coupled with some transition to defensive systems, but much lower levels of both offensive and defensive.

What I am concerned about is that we are going in precisely the opposite direction. We are going up on the offensive weapons with the D-5, MX, Midgetman, and on and on, and the Soviets are doing quite the same. They are talking about upgrading or having follow-ons to the SS-18 and the SS-X-24 and the 25 and they are going up dramatically on their offensive side. We are talking about a vigorous SDI Program. We know they have an aggressive SDI Program. The real complaint is how do we slow everything down, get the offensive systems down and perhaps, to use Paul Nitze's phrase, negotiate a transition to a more defensive oriented system.

Unfortunately, the debate is always characterized in these polar camps—either you are for us or against us. You are either for SDI or you are for nuclear freeze and you must be opposed to what we are trying to do on the Modernization Program.

I was concerned about it. That is the reason I asked for a report about the policy implications. I was aware that the Chief of Naval Operations, Deputy Director for Strategic and Theater Nuclear Warfare stated in a memo in 1983.

"Unfortunately, there is little likelihood of a serious examination of the broad policy implications being done by anyone knowledgeable in the Office of the Secretary of Defense or Joint Chiefs of Staff." There was not much concern, it seemed to me exhibited about this.

Mr. PERLE. About what?

Senator COHEN. About policy implications of nuclear winter.

Mr. PERLE. There is a lot of concern about it.

Senator COHEN. I am talking about a memo that had this to say.

Then I looked at the DOD report and I did not find much in the way of policy implications. I had to turn to a study done by Palomar to find what kind of considerations do we need to take into account.

I know that you, in your testimony with Dr. Sagan before a House Interior Committee, cast some doubt on the need for much more money being spent in the research field, saying it is a bottomless pit.

While on the one hand you want more precision, you question validity of the need of pouring more money into research, which everybody else seems to think we need in order to get precise kinds of answers.

Mr. PERLE. I think we do need to invest sufficient money to reduce uncertainty at the lower end of the spectrum. That is, what is the smallest number of weapons that might cause a nuclear winter.

I do not believe that it is, given all the other priorities of research, that it is vital that we study second and third order biological consequences of nuclear war, but we are already well persuaded that nuclear war should be deterred.

When you ask what the policy implications are, the question is: Are we going to alter our policies, our policies of deterrence?

Our policies are flexible response, our approach to arms control, because we discovered there are biological consequences of nuclear war that we do not now understand?

I think the answer to that is no. If we were callous or indifferent to the consequences of a nuclear war, then you might persuade people to alter their policies if you could show effects that were not presently understood, but that is not the case.

So, it seems to me in that sense one could invest vast numbers to study consequences of nuclear war without any likelihood that would cause us to alter our fundamental policies.

Senator COHEN. It would have impact in terms of what you target.

Mr. PERLE. I believe, Senator Cohen, that we are on the right track in not targeting the cities as such.

Senator COHEN. May I interrupt a second?

I was intrigued with Senator Goldwater's suggestion about the targeting aspect. I find it incredible that we still talk in terms of surgical strikes in dealing with weapons of this size, to think we are firing silver bullets into fixed targets.

We are talking about, for example, Moscow's ABM system.

Would that likely be a target in a nuclear exchange?

Mr. PERLE. Certainly it would be targeted in all sorts of nuclear wars that one can imagine.

Senator COHEN. I assume many of our cities—Senator Wilson is not here, I do not want to alarm him—San Diego along with Bangor or Bath, there are a host of cities with military facilities that would be prime targets for the Soviets and for us.

When we talk about hitting primarily military targets, we really are deceiving ourselves into thinking that only those soldiers who wear the blue uniform sitting in the room today, the Air Force officers, are going to be hit. We are talking about major population centers going up.

Mr. PERLE. I do not find the prospect of striking population centers very appealing.

Senator COHEN. They are going to be hit, though.

Mr. PERLE. One of the reasons why I do not much care for the idea of mutual assured destruction.

Senator COHEN. The fact is, when we talk about moving toward counterforce, countersilo strike forces, we are really deluding ourselves into suggesting only military targets would be hit and population centers are not really going to be affected.

The fact is they are going to be fine targets, no matter what strategy. We are going to hit Moscow, they are going to hit Washington. We are talking about major cities going up in smoke.

For us to say we are really moving toward a more limited type of attack, I really do not think is credible.

Mr. PERLE. This is something you might want to pursue in closed session. But we are moving in that direction. I think we can move even further in that direction.

We are certainly not going to move in that direction if we revert to the idea that either nuclear winter or other concerns about nuclear war should cause us to target the cities of the Soviet Union in order to assure that massive destruction.

Senator COHEN. I do not think it logically follows. I am not suggesting that we simply start targeting cities and that is our form of deterrence. I frankly think a case can be made that you can have some deterrent value from an SDI program, perhaps. So, I do not write it off.

By the same token, I think we ought not to think that we are going to go forward to a new targeting strategy based on nuclear winter to just hit military sites, because I do not believe that to be the case.

Mr. **PERLE**. I say nuclear winter reinforces what I thought was a sensible trend over the last dozen years or so which is to move away from the earlier doctrine that the way to protect the United States was by remaining poised to destroy the civilian population of the Soviet Union. That strikes me as a bankruptcy morally and strategically.

We are moving away from it and we ought to continue to move away.

Senator Goldwater invited us to comment on what each of us have had to say. I have only one small point to make in response to Professor Sagan's last remark.

It is not the case, Dr. Sagan, that the United States and the Soviet Union have been steadily increasing their nuclear weapon systems since the beginning.

Dr. **SAGAN**. I said sum total.

Mr. **PERLE**. The sum total has gone up because the Soviet increases exceeded the American decreases. That seems to me a rather important way of stating it.

Dr. **SAGAN**. Let us talk about strategic weapons.

Do you think the number of American strategic weapons since the sixties has gone down?

Mr. **PERLE**. The United States today possesses some 7,000 fewer weapons than we had in 1960.

Dr. **SAGAN**. Since the 1960's has the number of strategic weapons in the U.S. arsenal gone down in any year?

Mr. **PERLE**. The number of strategic and tactical weapons has gone down.

Dr. **SAGAN**. You still do not answer my question.

Mr. **PERLE**. Your question also entails a distinction that misses the point. The point is that there is an impression that the number of nuclear weapons has been steadily increasing when in fact the United States today possesses fewer weapons than in 1960.

Dr. **SAGAN**. So, you are pleased with the policies of the Kennedy and Johnson administrations?

That is excellent. I am glad to hear it. I am sure it is clear from the way you have ducked the question, and as Department of Defense reports clearly show, the number of U.S. strategic weapons since the 1960's has increased every year and the decrease in the 1960's, was that due to some great moral rectitude on the part of the United States?

My understanding is that it was primarily due or at least in major part due to the conversion from bombers which could carry very large payloads to missiles which would carry much smaller payloads.

Also, there was a need to reprocess fusion material because the new delivery systems required new nuclear weapons and the triggers had to be gotten from somewhere. So, the idea that the United States has done something wonderful and the Soviets something awful in nuclear weapons arsenals does not bear close scrutiny.

I know you and the Secretary of Defense and the Secretary of State and many others keep making statements blurring distinction between strategic and tactical and blurring the difference between the 1960's and today.

The statement that cities are not targeted per se is a very serious remark. It does very little good to those who are destroyed to be told that they were not targeted per se, or, as you said, you do not target civilians as such.

There is this awful coincidence that many strategic targets happen to be in proximity to or colocated with cities, as Senator Cohen mentioned.

The idea that we have nothing to worry about because there is a change in U.S. targeting policy so that cities are less targeted than before does very little to assuage the concerns of many people.

The issue is: Does the United States target enough cities to bring about nuclear winter, not do we target fewer cities than we did earlier?

As I said before, it is not simply a question of the United States. Does the Soviet Union target cities? How well acquainted are you with the Soviet targeting plans?

I suspect there are some limitations to your knowledge of Soviet targeting, and Soviet targeting is intimately connected with the safety of the planet in terms of nuclear winter.

And likewise, as I said before, the British, French, and Chinese also target. So, this is very cold comfort that the United States may target fewer cities than we had before.

If you really wish to reassure people, we have to know how many cities and what sorts and under what circumstances. Of course, I recognize that this is classified information, highly classified, and for very good reason it is classified.

Nevertheless, bland assurances on this matter of a qualitative sort, highly imprecise, do not carry much conviction in any public debate.

Mr. **Perle**. I do not believe my assurances were planned or intended to be assurances. I simply made the point we are moving in the direction I thought Senator Nunn and others on the committee might welcome and I should have thought you would welcome, too.

It seems to me clearly nothing we can do is going to satisfy you.

Dr. **Sagan**. On the contrary, there is a great deal you can do to satisfy me—and that is to be in favor of a massive bilateral verifiable reduction in the arsenals of the United States and the Soviet Union and to devote a tiny fraction of the amount of money you are willing to spend on star wars on verification technology.

Mr. **Perle**. If that is all it takes to satisfy you, you can go away from this hearing a happy man. We have consistently proposed significant reductions in nuclear arsenals. We did not get a lot of support, I might say, from you.

That is our position on the table in Geneva. As a matter of fact, I recall sitting next to you in a hearing in which you denounced the administration for sending to Geneva negotiators who, you said, were not serious about achieving agreement while we have had on the table proposals for deep reductions and the Soviets refused to discuss it.

Dr. **Sagan**. I was asked if I was in charge, a highly unlikely circumstance, what recommendations would I make?

I said the first thing I would do is send to Geneva people who have shown serious commitment to arms reduction.

Chairman **Goldwater**. All right, we will get back to questions. Senator Hart?

Senator **Hart**. Dr. Sagan, let me see if I can summarize what we have heard here today.

You and others have discovered in recent years that there is a collateral result of a nuclear exchange between the superpowers previously unquantified, which we call nuclear winter. It has to do with reduction in temperature sufficient to reduce food available to many nations on Earth and have other dire consequences to the survival of the human race and other species, in response, Mr. Perle says—and I will try to be as fair as I can—we are doing everything we can do to prevent nuclear war, we are pursuing weapons programs that enhance our deterrence, we are negotiating weapon systems and we are even for the first time in a long time pursuing a possibility of destroying nuclear weapons before they strike anyone.

Therefore, I think essentially Mr. Perle's statement to all this discovery that you have presented here and previously is: so what.

What is it that you have told us that should affect the policy of this administration at all?

We do not want nuclear war. We are doing our very best in every way we can to prevent it at the bargaining table, weapon systems, defensive systems, and research.

Just to say nuclear war is even more horrible than we have thought of before cannot possibly have an effect on this administration's policy.

Presuming that is a relatively fair restatement of Mr. Perle's position, what is your response to that?

Dr. **Sagan**. My response, first off, is the strategic defense initiative does not solve the problem and has a very high likelihood of making it much worse.

Senator **Hart**. Mr. Perle today agrees with that. He has not always in the past, but today he agrees.

Dr. **Sagan**. I did not actually hear him say it would make the problem much worse. If he does agree, I am delighted to hear it.

Second, I say, Senator Hart, that it is a very peculiar posture for the administration, which claims to be devoted to making massive cuts in nuclear weapons, to increase the number of strategic weapons every year that they are in office.

If you make a projection with the currently planned nuclear weapons delivery systems into the future, you will find a massive increase in the United States arsenal which, of course, is matched by a massive increase in the Soviet strategic arsenal.

My sense is that it is immensely foolish to have anything like the present number of nuclear weapons.

Senator **Hart**. In a sense, we are doing our best to reduce those through negotiations.

Dr. **Sagan**. Right, but the way we reduce it meanwhile is by increasing our nuclear weapons.

Mr. PERLE. I would like to know what these massive increases are that he is referring to.

Would you describe those massive increases?

Dr. SAGAN. Let me ask you how many strategic weapons are there in the U.S. arsenal at the present time?

How many will there be in 1989?

Mr. PERLE. I take it that you have chosen to respond in that way because you do not know what massive increases you are talking about.

Dr. SAGAN. I notice you have avoided the question.

Mr. PERLE. You made the assertion that there are going to be massive increases.

Do you mean to back that up?

Dr. SAGAN. Yes, I certainly do. If you wish to look at "Nuclear Battlefields" by Arkin, and others, you will find a confirmation of what I have just said.

But how many are there now and how many will there be in 1989 with presently approved weapons systems?

[The information follows:]

Dr. SAGAN. According to the recently published "Nuclear Weapons Databook" by William M. Arkin, Thomas B. Cochran, and Milton M. Hoenig (Volume I, U.S. Nuclear Forces and Capabilities, (Cambridge, MA: Ballinger, 1984) and summarized in the Bulletin of the Atomic Scientists August/September, 1984), the number of deliverable strategic warheads in the U.S. at the end of 1984 was 12,968, and the number anticipated by the end of 1989 is 15,533, an increment of 2,063 weapons. This increment by itself is nearly sufficient to destroy every city on the planet Earth.

Mr. PERLE. It depends on a lot of uncertainties.

Dr. SAGAN. Give us a probable error.

Mr. PERLE. The numbers are roughly comparable.

Dr. SAGAN. To what?

Mr. PERLE. To the current inventory. The fact is you are referring me to the book because you cannot answer the question. You make these cavalier assertions you cannot back up.

There are no massive increases. This committee knows that because it approves the programs. Most of what we are doing entails substitution of older weapons with newer weapons. Whether there is some modest increase——

Dr. SAGAN. How much is modest?

Mr. PERLE. I think it was entirely fair for me to ask you to prove your assertion.

Dr. SAGAN. You are an Assistant Secretary of Defense. Surely you have at your fingertips these numbers.

Why can't you answer?

Mr. PERLE. As it happens, I do not have the answer at my fingertips.

Dr. SAGAN. That is curious.

Mr. PERLE. The precise number is rather close to the current number.

Dr. SAGAN. Which is what?

Mr. PERLE. As a matter of fact, the exact numbers are numbers we do not disclose.

Dr. SAGAN. I am happy to have the answer with a probable error.

Mr. PERLE. Let the record show that when asked what these massive increases are, I was referred to a book by Mr. Arkin.

Chairman Goldwater. Senator Hart, have you finished?

Senator Hart. Yes, sir.

Chairman Goldwater. Senator Cohen, have you finished?

Senator Cohen. I have no further questions.

Chairman Goldwater. Gentlemen, this has been very, very interesting. I do not know if we have solved the problem of nuclear winter. It has been interesting.

I would like to see all countries stop building nuclear weapons. In fact, I do not believe it is physically possible for either side to launch more than about 10 percent above what they have in the silos now.

So, whether we have 100,000 or 10,000 really does not bother me. They have enough in the ground to do a lot of damage.

Thank you very much for coming here today. We really appreciate it. We may call on you again. This will be forever before us. Thank you.

[Material submitted for the record by Dr. Sagan follows:]

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NUCLEAR WAR AND CLIMATIC CATASTROPHE: SOME POLICY IMPLICATIONS

Carl Sagan

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Carl Sagan

NUCLEAR WAR AND CLIMATIC CATASTROPHE: SOME POLICY IMPLICATIONS

> It is not even impossible to imagine that the effects of an atomic war fought with greatly perfected weapons and pushed by the utmost determination will endanger the survival of man.
>
> Edward Teller
> *Bulletin of the Atomic Scientists*, February 1947

> The extreme danger to mankind inherent in the proposal by [Edward Teller and others to develop thermonuclear weapons] wholly outweighs any military advantage.
>
> J. Robert Oppenheimer, *et al.*
> *Report of the General Advisory Committee, AEC*
> October 1949

> The fact that no limits exist to the destructiveness of this weapon makes its very existence and the knowledge of its construction a danger to humanity. . . . It is . . . an evil thing.
>
> Enrico Fermi and I. I. Rabi
> Addendum, *ibid.*

> A very large nuclear war would be a calamity of indescribable proportions and absolutely unpredictable consequences, with the uncertainties tending toward the worse. . . . All-out nuclear war would mean the destruction of contemporary civilization, throw man back centuries, cause the deaths of hundreds of millions or billions of people, and, with a certain degree of probability, would cause man to be destroyed as a biological species . . .
>
> Andrei Sakharov
> *Foreign Affairs*, Summer 1983

Apocalyptic predictions require, to be taken seriously, higher standards of evidence than do assertions on other matters

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where the stakes are not as great. Since the immediate effects of even a single thermonuclear weapon explosion are so devastating, it is natural to assume—even without considering detailed mechanisms—that the more or less simultaneous explosion of ten thousand such weapons all over the Northern Hemisphere might have unpredictable and catastrophic consequences.

And yet, while it is widely accepted that a full nuclear war might mean the end of civilization at least in the Northern Hemisphere, claims that nuclear war might imply a reversion of the human population to prehistoric levels, or even the extinction of the human species, have, among some policymakers at least, been dismissed as alarmist or, worse, irrelevant. Popular works that stress this theme, such as Nevil Shute's *On the Beach,* and Jonathan Schell's *The Fate of the Earth,* have been labeled disreputable. The apocalyptic claims are rejected as unproved and unlikely, and it is judged unwise to frighten the public with doomsday talk when nuclear weapons are needed, we are told, to preserve the peace. But, as the above quotations illustrate, comparably dire warnings have been made by respectable scientists with diverse political inclinations, including many of the American and Soviet physicists who conceived, devised and constructed the world nuclear arsenals.

Part of the resistance to serious consideration of such apocalyptic pronouncements is their necessarily theoretical basis. Understanding the long-term consequences of nuclear war is not a problem amenable to experimental verification—at least not more than once. Another part of the resistance is psychological. Most people—recognizing nuclear war as a grave and terrifying prospect, and nuclear policy as immersed in technical complexities, official secrecy and bureaucratic inertia—tend to practice what psychiatrists call denial: putting the agonizing problem out of our heads, since there seems nothing we can do about it. Even policymakers must feel this temptation from time to time. But for policymakers there is another concern: if it turns out that nuclear war could end our civilization or our species, such a finding might be considered a retroactive rebuke to those responsible, actively or passively, in the past or in the present, for the global nuclear arms race.

The stakes are too high for us to permit any such factors to influence our assessment of the consequences of nuclear war. If nuclear war now seems significantly more catastrophic than has generally been believed in the military and policy communities, then serious consideration of the resulting implications is urgently called for.

It is in that spirit that this article seeks, first, to present a short summary, in lay terms, of the climatic and biological consequences of nuclear war that emerge from extensive scientific studies conducted over the past two years, the essential conclusions of which have now been endorsed by a large number of scientists. These findings were presented in detail at a special conference in Cambridge, Mass., involving almost 100 scientists on April 22–26, 1983, and were publicly announced at a conference in Washington, D.C., on October 31 and November 1, 1983. They have been reported in summary form in the press, and a detailed statement of the findings and their bases will be published in *Science*.[1] The present summary is designed particularly for the lay reader.

Following this summary, I explore the possible strategic and policy implications of the new findings.* They point to one apparently inescapable conclusion: the necessity of moving as rapidly as possible to reduce the global nuclear arsenals below levels that could conceivably cause the kind of climatic catastrophe and cascading biological devastation predicted by the new studies. Such a reduction would have to be to a small percentage of the present global strategic arsenals.

II

The central point of the new findings is that the long-term consequences of a nuclear war could constitute a global climatic catastrophe.

The immediate consequences of a single thermonuclear weapon explosion are well known and well documented—fireball radiation, prompt neutrons and gamma rays, blast, and fires.[2] The Hiroshima bomb that killed between 100,000 and 200,000 people was a fission device of about 12 kilotons yield (the explosive equivalent of 12,000 tons of TNT). A modern thermonuclear warhead uses a device something like the Hiroshima bomb as the trigger—the "match" to light the fusion reaction. A typical thermonuclear weapon now has a yield of about 500 kilotons (or 0.5 megatons, a megaton being the explosive equivalent of a million tons of TNT). There are many weapons in the 9 to 20 megaton range in the strategic arsenals of the United States and the Soviet Union today. The highest-yield weapon ever exploded is 58 megatons.

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[1] R. P. Turco, O. B. Toon, T. P. Ackerman, J. B. Pollack and Carl Sagan [TTAPS], "Global Atmospheric Consequences of Nuclear War," *Science*, in press; P. R. Ehrlich, M. A. Harwell, Peter H. Raven, Carl Sagan, G. M. Woodwell, *et al.*, "The Long-Term Biological Consequences of Nuclear War," *Science*, in press.

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This article would not have been possible without the high scientific competence and dedication of my co-authors on the TTAPS study, Richard P. Turco, Owen B. Toon, Thomas P. Ackerman, and James B. Pollack, and my 19 coauthors of the accompanying scientific paper on the long-term biological consequences of nuclear war. Finally, I wish to thank my Soviet colleagues, V. V. Alexandrov, E. I. Chazov, G. S. Golitsyn, and E. P. Velikhov among others, for organizing independent confirmations of the probable existence of a post-nuclear-war climatic catastrophe, and for helping to generate a different kind of climate—one of mutual concern and cooperation that is essential if we are to emerge safely from the trap that our two nations have jointly set for ourselves, our civilization, and our species.

Strategic nuclear weapons are those designed for delivery by ground-based or submarine-launched missiles, or by bombers, to targets in the adversary's homeland. Many weapons with yields roughly equal to that of the Hiroshima bomb are today assigned to "tactical" or "theater" military missions, or are designated "munitions" and relegated to ground-to-air and air-to-air missiles, torpedoes, depth charges and artillery. While strategic weapons often have higher yields than tactical weapons, this is not always the case.[3] Modern tactical or theater missiles (e.g., Pershing II, SS-20) and air support weapons (e.g., those carried by F-15 or MiG-23 aircraft) have sufficient range to make the distinction between "strategic" and "tactical" or "theater" weapons increasingly artificial. Both categories of weapons can be delivered by land-based missiles, sea-based missiles, and aircraft; and by intermediate-range as well as intercontinental delivery systems. Nevertheless, by the usual accounting, there are around 18,000 strategic thermonuclear weapons (warheads) and the equivalent number of fission triggers in the American and Soviet strategic arsenals, with an aggregate yield of about 10,000 megatons.

The total number of nuclear weapons (strategic plus theater and tactical) in the arsenals of the two nations is close to 50,000, with an aggregate yield near 15,000 megatons. For convenience, we here collapse the distinction between strategic and theater weapons, and adopt, under the rubric "strategic," an aggregate yield of 13,000 megatons. The nuclear weapons of the rest of the world—

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[2] Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear War*, 3rd ed., Washington: Department of Defense, 1977.

[3] The "tactical" Pershing I, for example, is listed as carrying warheads with yields as high as 400 kilotons, while the "strategic" Poseidon C-3 is listed with a yield of only 40 kilotons. *World Armaments and Disarmament, SIPRI Yearbook 1982*, Stockholm International Peace Research Institute, London: Taylor and Francis, 1982; J. Record, *U.S. Nuclear Weapons in Europe*, Washington: Brookings Institution, 1974.

mainly Britain, France and China—amount to many hundred warheads and a few hundred megatons of additional aggregate yield.

No one knows, of course, how many warheads with what aggregate yield would be detonated in a nuclear war. Because of attacks on strategic aircraft and missiles, and because of technological failures, it is clear that less than the entire world arsenal would be detonated. On the other hand, it is generally accepted, even among most military planners, that a "small" nuclear war would be almost impossible to contain before it escalated to include much of the world arsenals.[4] (Precipitating factors include command and control malfunctions, communications failures, the necessity for instantaneous decisions on the fates of millions, fear, panic and other aspects of real nuclear war fought by real people.) For this reason alone, any serious attempt to examine the possible consequences of nuclear war must place major emphasis on large-scale exchanges in the five-to-seven-thousand-megaton range, and many studies have done so.[5] Many of the effects described below, however, can be triggered by much smaller wars.

The adversary's strategic airfields, missile silos, naval bases, submarines at sea, weapons manufacturing and storage locales, civilian and military command and control centers, attack assessment and early warning facilities, and the like are probable targets ("counterforce attack"). While it is often stated that cities are not targeted "per se," many of the above targets are very near or colocated with cities, especially in Europe. In addition, there is an industrial targeting category ("countervalue attack"). Modern nuclear doctrines require that "war-supporting" facilities be attacked. Many of these facilities are necessarily industrial in nature and engage a work force of considerable size. They are almost always situated near major transportation centers, so that raw materials and finished products can be efficiently transported to other industrial sectors, or to forces in the field. Thus, such facilities are, almost by definition, cities, or near or within cities. Other "war-supporting" targets may include the transportation systems themselves (roads, canals, rivers, railways, civilian airfields, etc.), petroleum refineries storage sites and pipelines, hydroelectric plants, radio and television transmitters and the like. A major countervalue attack therefore might involve almost all large cities in the United States and the Soviet Union, and possibly most of the large cities in the Northern Hemisphere.[6] There are fewer than 2,500 cities in the world with populations over 100,000 inhabitants, so the devastation of all such cities is well within the means of the world nuclear arsenals.

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[4] See, e.g., D. Ball, Adelphi Paper 169, London: International Institute for Strategic Studies, 1981; P. Bracken and M. Shubik, in *Technology in Society*, Vol. 4, 1982, p. 155.

[5] National Academy of Sciences/National Research Council, *Long-term Worldwide Effects of Multiple Nuclear Weapons Detonations*, Washington: National Academy of Sciences, 1975; Office of Technology Assessment, *The Effects of Nuclear War*, Washington, 1979; J. Peterson (Ed.), *Nuclear War: The Aftermath*, special issue *Ambio*, Vol. 11, Nos. 2–3, Royal Swedish Academy of Sciences, 1982; R. P. Turco, *et al.*, *loc. cit.* footnote 1; S. Bergstrom, *et al.*, *Effects of Nuclear War on Health and Health Services*, Rome: World Health Organization, Publication No. A36.12, 1983; National Academy of Sciences, new 1983 study in press.

Recent estimates of the immediate deaths from blast, prompt radiation, and fires in a major exchange in which cities were targeted range from several hundred million to 1.1 billion people—the latter estimate is in a World Health Organization study in which targets were assumed not to be restricted entirely to NATO and Warsaw Pact countries.[7] Serious injuries requiring immediate medical attention (which would be largely unavailable) would be suffered by a comparably large number of people, perhaps an additional 1.1 billion.[8] Thus it is possible that something approaching half the human population on the planet would be killed or seriously injured by the direct effects of the nuclear war. Social disruption; the unavailability of electricity, fuel, transportation, food deliveries, communications and other civil services; the absence of medical care; the decline in sanitation measures; rampant disease and severe psychiatric disorders would doubtless collectively claim a significant number of further victims. But a range of additional effects—some unexpected, some inadequately treated in earlier studies, some uncovered only recently—now make the picture much more somber still.

Because of current limitations on missile accuracy, the destruction of missile silos, command and control facilities, and other hardened sites requires nuclear weapons of fairly high yield exploded as groundbursts or as low airbursts. High-yield groundbursts will vaporize, melt and pulverize the surface at the target area and propel large quantities of condensates and fine dust into the upper troposphere and stratosphere. The particles are chiefly entrained in the rising fireball; some ride up the stem of the mushroom cloud. Most military targets, however, are not very hard. The destruction of cities can be accomplished, as demonstrated at Hiroshima and Nagasaki, by lower-yield explosions less than a kilometer above the surface. Low-yield airbursts over cities or near forests will tend to produce massive fires, some of them over areas of 100,000 square kilometers or more. City fires generate enormous quantities of black oily smoke which rise at least into the upper part of the lower atmosphere, or troposphere. If firestorms occur, the smoke column rises vigorously, like the draft in a fireplace, and may carry some of the soot into the lower part of the upper atmosphere, or stratosphere. The smoke from forest and grassland fires would initially be restricted to the lower troposphere.

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[6] See, e.g., J. Peterson, *op. cit.* footnote 5.

[7] S. Bergstrom, *op. cit.* footnote 5.

[8] *Ibid.*

The fission of the (generally plutonium) trigger in every thermonuclear weapon and the reactions in the (generally uranium-238) casing added as a fission yield "booster" produce a witch's brew of radioactive products, which are also entrained in the cloud. Each such product, or radioisotope, has a characteristic "half-life" (defined as the time to decay to half its original level of radioactivity). Most of the radioisotopes have very short half-lives and decay in hours to days. Particles injected into the stratosphere, mainly by high-yield explosions, fall out very slowly—characteristically in about a year, by which time most of the fission products, even when concentrated, will have decayed to much safer levels. Particles injected into the troposphere by low-yield explosions and fires fall out more rapidly—by gravitational settling, rainout, convection, and other processes—before the radioactivity has decayed to moderately safe levels. Thus rapid fallout of tropospheric radioactive debris tends to produce larger doses of ionizing radiation than does the slower fallout of radioactive particles from the stratosphere.

Nuclear explosions of more than one-megaton yield generate a radiant fireball that rises through the troposphere into the stratosphere. The fireballs from weapons with yields between 100 kilotons and one megaton will partially extend into the stratosphere. The high temperatures in the fireball chemically ignite some of the nitrogen in the air, producing oxides of nitrogen, which in turn chemically attack and destroy the gas ozone in the middle stratosphere. But ozone absorbs the biologically dangerous ultraviolet radiation from the Sun. Thus the partial depletion of the stratospheric ozone layer, or "ozonosphere," by high-yield nuclear explosions will increase the flux of solar ultraviolet radiation at the surface of the Earth (after the soot and dust have settled out). After a nuclear war in which thousands of high-yield weapons are detonated, the increase in biologically dangerous ultraviolet light might be several hundred percent. In the more dangerous shorter wavelengths, larger increases would occur. Nucleic acids and proteins, the fundamental molecules for life on Earth, are especially sensitive to ultraviolet radiation. Thus, an increase of the solar ultraviolet flux at the surface of the Earth is potentially dangerous for life.

These four effects—obscuring smoke in the troposphere, obscuring dust in the stratosphere, the fallout of radioactive debris, and the partial destruction of the ozone layer—constitute the four known principal adverse environmental consequences that occur after a nuclear war is "over." There may be others about which we are still ignorant. The dust and, especially, the dark soot absorb ordinary visible light from the Sun, heating the atmosphere and cooling the Earth's surface.

All four of these effects have been treated in our recent scientific investigation.[9] The study, known from the initials of its authors as TTAPS, for the first time demonstrates that severe and prolonged low temperatures would follow a nuclear war. (The study also explains the fact that no such climatic effects were detected after the detonation of hundreds of megatons during the period of U.S.-Soviet atmospheric testing of nuclear weapons, ended by treaty in 1963: the explosions were sequential over many years, not virtually simultaneous; and, occurring over scrub desert, coral atolls, tundra and wasteland, they set no fires.) The new results have been subjected to detailed scrutiny, and half a dozen confirmatory calculations have now been made. A special panel appointed by the National Academy of Sciences to examine this problem has come to similar conclusions.[10]

Unlike many previous studies, the effects do not seem to be restricted to northern mid-latitudes, where the nuclear exchange would mainly take place. There is now substantial evidence that the heating by sunlight of atmospheric dust and soot over northern mid-latitude targets would profoundly change the global circulation. Fine particles would be transported across the equator in weeks, bringing the cold and the dark to the Southern Hemisphere. (In addition, some studies suggest that over 100 megatons would be dedicated to equatorial and Southern Hemisphere targets, thus generating fine particles locally.)[11] While it would be less cold and less dark at the ground in the Southern Hemisphere than in the Northern, massive climatic and environmental disruptions may be triggered there as well.

In our studies, several dozen different scenarios were chosen, covering a wide range of possible wars, and the range of uncertainty in each key parameter was considered (e.g., to describe how many fine particles are injected into the atmosphere). Five representative cases are shown in Table 1, below, ranging from a small low-yield attack exclusively on cities, utilizing, in yield, only 0.8 percent of the world strategic arsenals, to a massive exchange involving 75

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[9] R. P. Turco, *et al.*, *loc. cit.* footnote 1.

[10] National Academy of Sciences, 1983, *loc. cit.* footnote 5.

[11] J. Peterson, *op. cit.* footnote 6.

TABLE 1

NUCLEAR EXCHANGE SCENARIOS

Case	Total Yield (MT)	% Yield Surface Bursts	% Yield Urban or Industrial Targets	Warhead Yield Range (MT)	Total Number of Explosions
1. Baseline Case, countervalue and counterforce(a)	5,000	57	20	0.1–10	10,400
11. 3,000 MT nominal, counterforce only(b)	3,000	50	0	1 –10	2,250
14. 100 MT nominal, countervalue only(c)	100	0	100	0.1	1,000
16. 5000 MT "severe," counterforce only(b, d)	5,000	100	0	5 –10	700
17. 10,000 MT "severe," countervalue and counterforce(c, d)	10,000	63	15	0.1–10	16,160

a. In the Baseline Case, 12,000 square kilometers of inner cities are burned; on every square centimeter an average of 10 grams of combustibles are burned, and 1.1% of the burned material rises as smoke. Also, 230,000 square kilometers of suburban areas burn, with 1.5 grams consumed at each square centimeter and 3.6% rising as smoke.

b. In this highly conservative case, it is assumed that no smoke emission occurs, that not a blade of grass is burned. Only 25,000 tons of the fine dust is raised into the upper atmosphere for every megaton exploded.

c. In contrast to the Baseline Case, only inner cities burn, but with 10 grams per square centimeter consumed and 3.3% rising as smoke into the high atmosphere.

d. Here, the fine (submicron) dust raised into the upper atmosphere is 150,000 tons per megaton exploded.

percent of the world arsenals. "Nominal" cases assume the most probable parameter choices; "severe" cases assume more adverse parameter choices, but still in the plausible range.

Predicted continental temperatures in the Northern Hemisphere vary after the nuclear war according to the curves shown in Figure 1 on the following page. The high heat-retention capacity of water guarantees that oceanic temperatures will fall at most by a few degrees. Because temperatures are moderated by the adjacent oceans, temperature effects in coastal regions will be less extreme than in continental interiors. The temperatures shown in Figure 1 are average values for Northern Hemisphere land areas.

Even much smaller temperature declines are known to have serious consequences. The explosion of the Tambora volcano in Indonesia in 1815 led to an average global temperature decline of only 1°C, due to the obscuration of sunlight by the fine dust propelled into the stratosphere; yet the hard freezes the following year were so severe that 1816 has been known in Europe and America as "the year without a summer." A 1°C cooling would

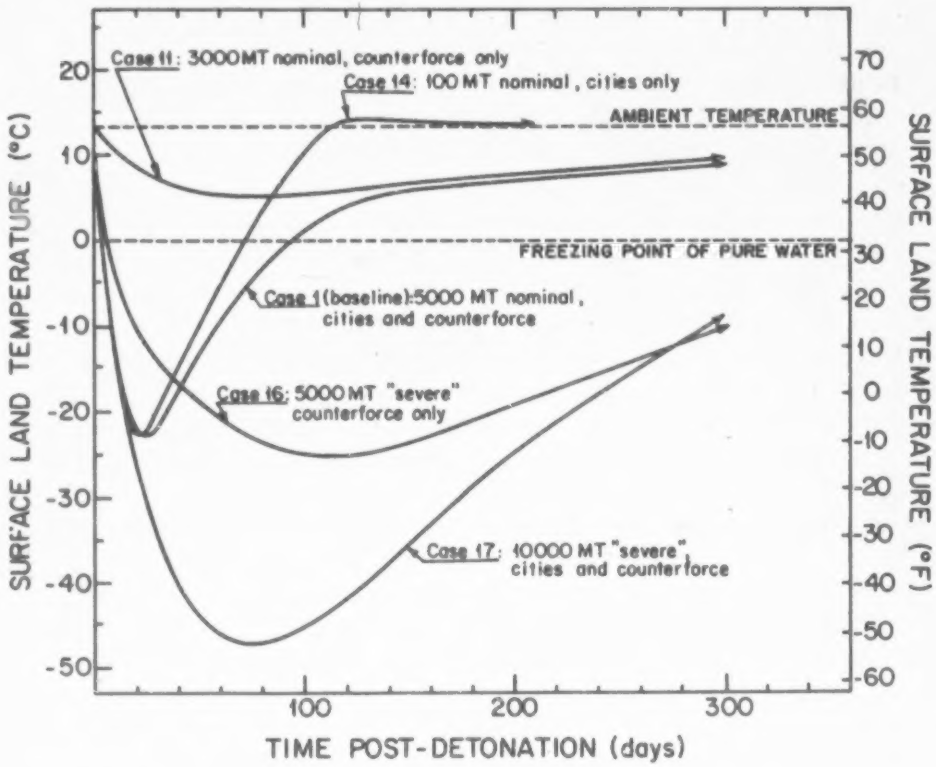

FIGURE 1

TEMPERATURE EFFECTS OF NUCLEAR WAR CASES

NOTE: In this Figure, the average temperature of Northern Hemisphere land areas (away from coastlines) is shown varying with time after the five Cases of nuclear war defined in Table 1. The "ambient" temperature is the average in the Northern Hemisphere over all latitudes and seasons: thus, normal winter temperatures at north temperature latitudes are lower than is shown, and normal tropical temperatures are higher than shown. Cases described as "nominal" assume the most likely values of parameters (such as dust particle size or the frequency of firestorms) that are imperfectly known. Cases marked "severe" represent adverse but not implausible values of these parameters. In Case 14 the curve ends when the temperatures come within a degree of the ambient values. For the four other Cases the curves are shown ending after 300 days, but this is simply because the calculations were not extended further. In these four Cases the curves will continue to the directions they are headed.

nearly eliminate wheat growing in Canada.[12] In the last thousand years, the maximum global or Northern Hemisphere temperature deviations have been around 1°C. In an Ice Age, a typical long-term temperature decline from preexisting conditions is about 10°C. Even the most modest of the cases illustrated in Figure 1 give temporary temperature declines of this order. The Baseline Case is much more adverse. Unlike the situation in an Ice Age, however, the global temperatures after nuclear war plunge rapidly and take only months to a few years to recover, rather than thousands of years. No new Ice Age is likely to be induced by a Nuclear Winter.

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[12] National Academy of Sciences, 1975, *op. cit.* footnote 5.

Because of the obscuration of the Sun, the daytime light levels can fall to a twilit gloom or worse. For more than a week in the northern mid-latitude target zone, it might be much too dark to see, even at midday. In Cases 1 and 14 (Table 1), hemispherically averaged light levels fall to a few percent of normal values, comparable to those at the bottom of a dense overcast. At this illumination, many plants are close to what is called the compensation point, the light level at which photosynthesis can barely keep pace with plant metabolism. In Case 17, illumination, averaged over the entire Northern Hemisphere, falls in daytime to about 0.1 percent of normal, a light level at which plants will not photosynthesize at all. For Cases 1 and especially 17, full recovery to ordinary daylight takes a year or more (Figure 1).

As the fine particles fall out of the atmosphere, carrying radioactivity to the ground, the light levels increase and the surface warms. The depleted ozone layer now permits ultraviolet light to reach the Earth's surface in increased proportions. The relative timing of the multitude of adverse consequences of a nuclear war is shown in Table 2, on the following page.

Perhaps the most striking and unexpected consequence of our study is that even a comparatively small nuclear war can have devastating climatic consequences, provided cities are targeted (see Case 14 in Figure 1; here, the centers of 100 major NATO and Warsaw Pact cities are burning). There is an indication of a very rough threshold at which severe climatic consequences are triggered—around a few hundred nuclear explosions over cities, for smoke generation, or around 2,000 to 3,000 high-yield surface bursts at, e.g., missile silos, for dust generation and ancillary fires. Fine particles can be injected into the atmosphere at increasing rates with only minor effects until these thresholds are crossed. Thereafter, the effects rapidly increase in severity.[13]

As in all calculations of this complexity, there are uncertainties. Some factors tend to work towards more severe or more prolonged effects; others tend to ameliorate the effects.[14] The detailed TTAPS calculations described here are one-dimensional; that is, they assume the fine particles to move vertically by all the appropriate

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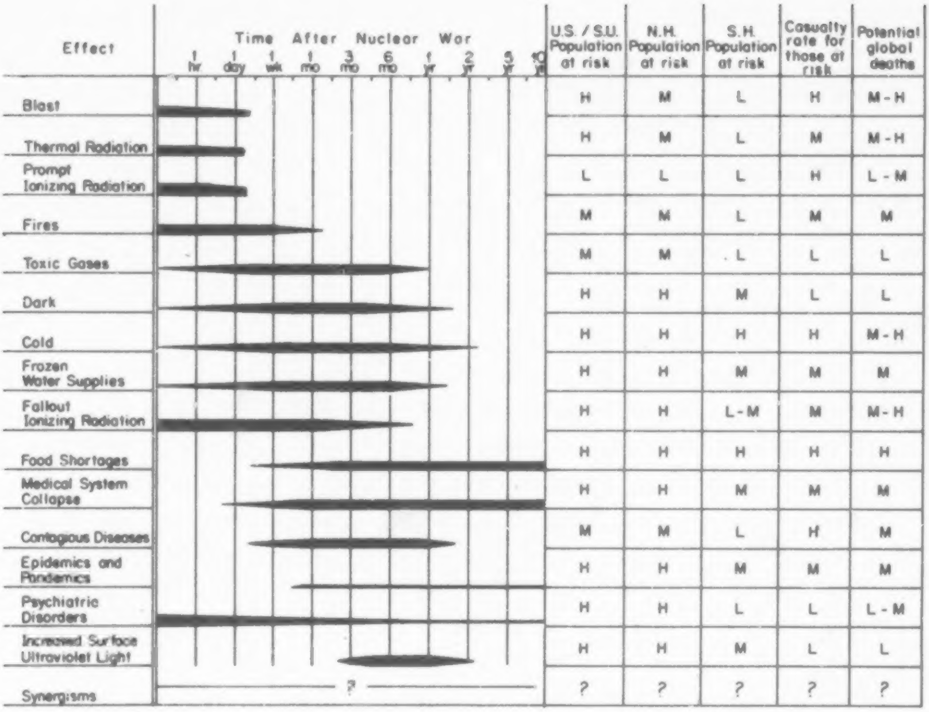
[13] The climatic threshold for smoke in the troposphere is about 100 million metric tons, injected essentially all at once; for sub-micron fine dust in the stratosphere, about the same.

[14] The slow warming of the Earth due to a CO_2 greenhouse effect attendant to the burning of fossil fuels should not be thought of as tempering the nuclear winter: the greenhouse temperature increments are too small and too slow.



Effect	U.S. / S.U. Population at risk	N.H. Population at risk	S.H. Population at risk	Casualty rate for those at risk	Potential global deaths
Blast	H	M	L	H	M - H
Thermal Radiation	H	M	L	M	M - H
Prompt Ionizing Radiation	L	L	L	H	L - M
Fires	M	M	L	M	M
Toxic Gases	M	M	L	L	L
Dark	H	H	M	L	L
Cold	H	H	H	H	M - H
Frozen Water Supplies	H	H	M	M	M
Fallout Ionizing Radiation	H	H	L - M	M	M - H
Food Shortages	H	H	H	H	H
Medical System Collapse	H	H	M	M	M
Contagious Diseases	M	M	L	H	M
Epidemics and Pandemics	H	H	M	M	M
Psychiatric Disorders	H	H	L	L	L - M
Increased Surface Ultraviolet Light	H	H	M	L	L
Synergisms	?	?	?	?	?

TABLE 2

EFFECTS OF THE BASELINE NUCLEAR WAR

NOTE: This is a schematic representation of the time scale for the effects, which are most severe when the thickness of the horizontal bar is greatest. The columns at the right indicate the degree of risk of the populations of the United States and the Soviet Union, the Northern Hemisphere, and the Southern Hemisphere—with H, M, and L standing for High, Medium, and Low respectively.

laws of physics, but neglect the spreading in latitude and longitude. When soot or dust is moved away from the reference locale, things get better there and worse elsewhere. In addition, fine particles can be transported by weather systems to other locales, where they are carried more rapidly down to the surface. That would ameliorate obscuration not just locally but globally. It is just this transport away from the northern mid-latitudes that involves the equatorial zone and the Southern Hemisphere in the effects of the nuclear war. It would be helpful to perform an accurate three-dimensional calculation on the general atmospheric circulation following a nuclear war. Preliminary estimates suggest that circulation might moderate the low temperatures in the Northern Hemisphere predicted in our calculations by some 30 percent, lessening somewhat the severity of the effects, but still leaving them at catastrophic levels (e.g., a 30°C rather than a 40°C temperature drop). To provide a small margin of safety, we neglect this correction in our subsequent discussion.

There are also effects that tend to make the results much worse: for example, in our calculations we assumed that rainout of fine particles occurred through the entire troposphere. But under realistic circumstances, at least the upper troposphere may be very dry, and any dust or soot carried there initially may take much longer to fall out. There is also a very significant effect deriving from the drastically altered structure of the atmosphere, brought about by the heating of the clouds and the cooling of the surface. This produces a region in which the temperature is approximately constant with altitude in the lower atmosphere and topped by a massive temperature inversion. Particles throughout the atmosphere would then be transported vertically very slowly—as in the present stratosphere. This is a second reason why the lifetime of the clouds of soot and dust may be much longer than we have calculated. If so, the worst of the cold and the dark might be prolonged for considerable periods of time, conceivably for more than a year. We also neglect this effect in subsequent discussion.

Nuclear war scenarios are possible that are much worse than the ones we have presented. For example, if command and control capabilities are lost early in the war—by, say, "decapitation" (an early surprise attack on civilian and military headquarters and communications facilities)—then the war conceivably could be extended for weeks as local commanders make separate and uncoordinated decisions. At least some of the delayed missile launches could be retaliatory strikes against any remaining adversary cities. Generation of an additional smoke pall over a period of weeks or longer following the initiation of the war would extend the magnitude, but especially the duration of the climatic consequences. Or it is possible that more cities and forests would be ignited than we have assumed, or that smoke emissions would be larger, or that a greater fraction of the world arsenals would be committed. Less severe cases are of course possible as well.

These calculations therefore are not, and cannot be, assured prognostications of the full consequences of a nuclear war. Many refinements in them are possible and are being pursued. But there is general agreement on the overall conclusions: in the wake of a nuclear war there is likely to be a period, lasting at least for months, of extreme cold in a radioactive gloom, followed—after the soot and dust fall out—by an extended period of increased ultraviolet light reaching the surface.[15]

We now explore the biological impact of such an assault on the global environment.

III

The immediate human consequences of nuclear explosions range from vaporization of populations near the hypocenter, to blast-generated trauma (from flying glass, falling beams, collapsing skyscrapers and the like), to burns, radiation sickness, shock and severe psychiatric disorders. But our concern here is with longer-term effects.

It is now a commonplace that in the burning of modern tall buildings, more people succumb to toxic gases than to fire. Ignition of many varieties of building materials, insulation and fabrics generates large amounts of such pyrotoxins, including carbon monoxide, cyanides, vinyl chlorides, oxides of nitrogen, ozone, dioxins, and furans. Because of differing practices in the use of such synthetics, the burning of cities in North America and Western Europe will probably generate more pyrotoxins than cities in the Soviet Union, and cities with substantial recent construction more than older, unreconstructed cities. In nuclear war scenarios in which a great many cities are burning, a significant pyrotoxin smog might persist for months. The magnitude of this danger is unknown.

The pyrotoxins, low light levels, radioactive fallout, subsequent ultraviolet light, and especially the cold are together likely to destroy almost all of Northern Hemisphere agriculture, even for the more modest Cases 11 and 14. A 12° to 15°C temperature reduction by itself would eliminate wheat and corn production in the United States, even if all civil systems and agricultural technology were intact.[16] With unavoidable societal disruption, and with the other environmental stresses just mentioned, even a 3,000-megaton "pure" counterforce attack (Case 11) might suffice. Realistically, many fires would be set even in such an attack (see below), and a 3,000-megaton war is likely to wipe out U.S. grain production. This would represent by itself an unprecedented global catastrophe: North American grain is the principal reliable source of export food on the planet, as well as an essential component of U.S. prosperity. Wars just before harvesting of grain and other staples would be incrementally worse than wars after harvesting. For many scenarios, the effects will extend (see Figure 2) into two or more growing seasons. Widespread fires and subsequent runoff of topsoil are among the many additional deleterious consequences extending for years after the war.

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[15] These results are dependent on important work by a large number of scientists who have previously examined aspects of this subject; many of these workers are acknowledged in the articles cited in footnote 1.

[16] David Pimentel and Mark Sorrells, private communication, 1983.

Something like three-quarters of the U.S. population lives in or near cities. In the cities themselves there is, on average, only about one week's supply of food. After a nuclear war it is conceivable that enough of present grain storage might survive to maintain, on some level, the present population for more than a year. But with the breakdown of civil order and transportation systems in the cold, the dark and the fallout, these stores would become largely inaccessible. Vast numbers of survivors would soon starve to death.

In addition, the sub-freezing temperatures imply, in many cases, the unavailability of fresh water. The ground will tend to be frozen to a depth of about a meter—incidentally making it unlikely that the hundreds of millions of dead bodies would be buried, even if the civil organization to do so existed. Fuel stores to melt snow and ice would be in short supply, and ice surfaces and freshly fallen snow would tend to be contaminated by radioactivity and pyrotoxins.

In the presence of excellent medical care, the average value of the acute lethal dose of ionizing radiation for healthy adults is about 450 rads. (As with many other effects, children, the infirm and the elderly tend to be more vulnerable.) Combined with the other assaults on survivors in the postwar environment, and in the probable absence of any significant medical care, the mean lethal acute dose is likely to decline to 350 rads or even lower. For many outdoor scenarios, doses within the fallout plumes that drift hundreds of kilometers downwind of targets are greater than the mean lethal dose. (For a 10,000-megaton war, this is true for more than 30 percent of northern mid-latitude land areas.) Far from targets, intermediate-timescale chronic doses from delayed radioactive fallout may be in excess of 100 rads for the baseline case. These calculations assume no detonations on nuclear reactors or fuel-reprocessing plants, which would increase the dose.

Thus, the combination of acute doses from prompt radioactive fallout, chronic doses from the delayed intermediate-timescale fallout, and internal doses from food and drink are together likely to kill many more by radiation sickness. Because of acute damage to bone marrow, survivors would have significantly increased vulnerability to infectious diseases. Most infants exposed to 100 rads as fetuses in the first two trimesters of pregnancy would suffer mental retardation and/or other serious birth defects. Radiation and some pyrotoxins would later produce neoplastic diseases and genetic damage. Livestock and domesticated animals, with fewer resources, vanishing food supplies and in many cases with greater sensitivity to the stresses of nuclear war than human beings, would also perish in large numbers.

These devastating consequences for humans and for agriculture would not be restricted to the locales in which the war would principally be "fought," but would extend throughout northern mid-latitudes and, with reduced but still significant severity, probably to the tropics and the Southern Hemisphere. The bulk of the world's grain exports originate in northern mid-latitudes. Many nations in the developing as well as the developed world depend on the import of food. Japan, for example, imports 75 percent of its food (and 99 percent of its fuel). Thus, even if there were no climatic and radiation stresses on tropical and Southern Hemisphere societies—many of them already at subsistence levels of nutrition—large numbers of people there would die of starvation.

As agriculture breaks down worldwide (possible initial exceptions might include Argentina, Australia and South Africa if the climatic impact on the Southern Hemisphere proved to be minimal), there will be increasing reliance on natural ecosystems—fruits, tubers, roots, nuts, etc. But wild foodstuffs will also have suffered from the effects of the war. At just the moment that surviving humans turn to the natural environment for the basis of life, that environment would be experiencing a devastation unprecedented in recent geological history.

Two-thirds of all species of plants, animals, and microorganisms on the Earth live within 25° of the equator. Because temperatures tend to vary with the seasons only minimally at tropical latitudes, species there are especially vulnerable to rapid temperature declines. In past major extinction events in the paleontological record, there has been a marked tendency for tropical organisms to show greater vulnerability than organisms living at more temperate latitudes.

The darkness alone may cause a collapse in the aquatic food chain in which sunlight is harvested by phytoplankton, phytoplankton by zooplankton, zooplankton by small fish, small fish by large fish, and, occasionally, large fish by humans. In many nuclear war scenarios, this food chain is likely to collapse at its base for at least a year and is significantly more imperiled in tropical waters. The increase in ultraviolet light available at the surface of the earth approximately a year after the war provides an additional major environmental stress that by itself has been described as having "profound consequences" for aquatic, terrestrial and other ecosystems.[17]

The global ecosystem can be considered an intricately woven fabric composed of threads contributed by the millions of separate species that inhabit the planet and interact with the air, the water and the soil. The system has developed considerable resiliency, so that pulling a single thread is unlikely to unravel the entire fabric. Thus, most ordinary assaults on the biosphere are unlikely to have catastrophic consequences. For example, because of natural small changes in stratospheric ozone abundance, organisms have probably experienced, in the fairly recent geologic past, ten percent fluctuations in the solar near-ultraviolet flux (but not fluctuations by factors of two or more). Similarly, major continental temperature changes of the magnitude and extent addressed here may not have been experienced for tens of thousands and possibly not for millions of years. We have no experimental information, even for aquaria or terraria, on the simultaneous effects of cold, dark, pyrotoxins, ionizing radiation, and ultraviolet light as predicted in the TTAPS study.

Each of these factors, taken separately, may carry serious consequences for the global ecosystem: their interactions may be much more dire still. Extremely worrisome is the possibility of poorly understood or as yet entirely uncontemplated synergisms (where the net consequences of two or more assaults on the environment are much more than the sum of the component parts). For example, more than 100 rads (and possibly more than 200 rads) of external and ingested ionizing radiation is likely to be delivered in a very large nuclear war to all plants, animals and unprotected humans in densely populated regions of northern mid-latitudes. After the soot and dust clear, there can, for such wars, be a 200 to 400 percent increment in the solar ultraviolet flux that reaches the ground, with an increase of many orders of magnitude in the more dangerous shorter-wavelength radiation. Together, these radiation assaults are likely to suppress the immune systems of humans and other species, making them more vulnerable to disease. At the same time, the high ambient-radiation fluxes are likely to produce, through mutation, new varieties of microorganisms, some of which might become pathogenic. The preferential radiation sensitivity of birds and other insect predators would enhance the proliferation of herbivorous and pathogen-carrying insects. Carried by vectors with high radiation tolerance, it seems possible that epidemics and global pandemics would propagate with no hope of effective mitigation by medical care, even with reduced population sizes and greatly restricted human mobility. Plants, weakened by low temperatures and low light levels, and other animals would likewise be vulnerable to preexisting and newly arisen pathogens.

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[17] C. H. Kruger, R. B. Setlow, *et al., Causes and Effects of Stratospheric Ozone Reduction: An Update*, Washington: National Academy of Sciences, 1982.

There are many other conceivable synergisms, all of them still poorly understood because of the complexity of the global ecosystem. Every synergism represents an additional assault, of unknown magnitude, on the global ecosystem and its support functions for humans. What the world would look like after a nuclear war depends in part upon the unknown synergistic interaction of these various adverse effects.

We do not and cannot know that the worst would happen after a nuclear war. Perhaps there is some as yet undiscovered compensating effect or saving grace—although in the past, the overlooked effects in studies of nuclear war have almost always tended toward the worst. But in an uncertain matter of such gravity, it is wise to contemplate the worst, especially when its probability is not extremely small. The summary of the findings of the group of 40 distinguished biologists who met in April 1983 to assess the TTAPS conclusions is worthy of careful consideration:[18]

> Species extinction could be expected for most tropical plants and animals, and for most terrestrial vertebrates of north temperate regions, a large number of plants, and numerous freshwater and some marine organisms. . . . Whether any people would be able to persist for long in the face of highly modified biological communities; novel climates; high levels of radiation; shattered agricultural, social, and economic systems; extraordinary psychological stresses; and a host of other difficulties is open to question. It is clear that the ecosystem effects *alone* resulting from a large-scale thermonuclear war could be enough to destroy the current civilization in at least the Northern Hemisphere. Coupled with the direct casualties of perhaps two billion people, the combined intermediate and long-term effects of nuclear war suggest that eventually there might be no human survivors in the Northern Hemisphere.
>
> Furthermore, the scenario described here is by no means the most severe that could be imagined with present world nuclear arsenals and those contemplated for the near future. In almost any realistic case involving nuclear exchanges between the superpowers, global environmental changes sufficient to cause an extinction event equal to or more severe than that at the close of the Cretaceous when the dinosaurs and many other species died out are likely. In that event, the possibility of the extinction of *Homo sapiens* cannot be excluded.

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[18] P. Ehrlich, *et al.*, *loc. cit.* footnote 1.

IV

The foregoing probable consequences of various nuclear war scenarios have implications for doctrine and policy. Some have argued that the difference between the deaths of several hundred million people in a nuclear war (as has been thought until recently to be a reasonable upper limit) and the death of every person on Earth (as now seems possible) is only a matter of one order of magnitude. For me, the difference is considerably greater. Restricting our attention only to those who die as a consequence of the war conceals its full impact.

If we are required to calibrate extinction in numerical terms, I would be sure to include the number of people in future generations who would not be born. A nuclear war imperils all of our descendants, for as long as there will be humans. Even if the population remains static, with an average lifetime of the order of 100 years, over a typical time period for the biological evolution of a successful species (roughly ten million years), we are talking about some 500 trillion people yet to come. By this criterion, the stakes are one million times greater for extinction than for the more modest nuclear wars that kill "only" hundreds of millions of people.

There are many other possible measures of the potential loss—including culture and science, the evolutionary history of the planet, and the significance of the lives of all of our ancestors who contributed to the future of their descendants. Extinction is the undoing of the human enterprise.

For me, the new results on climatic catastrophe raise the stakes of nuclear war enormously. But I recognize that there are those, including some policymakers, who feel that the increased level of fatalities has little impact on policy, but who nevertheless acknowledge that the newly emerging consequences of nuclear war may require changes in specific points of strategic doctrine. I here set down what seem to me some of the more apparent such implications, within the context of present nuclear stockpiles. The idea of a crude threshold, very roughly around 500 to 2,000 warheads, for triggering the climatic catastrophe will be central to some of these considerations. (Such a threshold applies only to something like the present distribution of yields in the strategic arsenals. Drastic conversion to very low-yield arsenals—see below—changes some of the picture dramatically.) I hope others will constructively examine these preliminary thoughts and explore additional implications of the TTAPS results.

1. *First Strike*. The MIRVing of missiles (the introduction of mul-

tiple warheads), improvements in accuracy, and other developments have increased the perceived temptation to launch a devastating first strike against land targets—even though both sides retain a powerful retaliatory force in airborne bombers and submarines at sea. Much current concern and national rhetoric is addressed to the first-strike capability of extant or proposed weapons systems. The mere capability of a first strike creates incentives for a preemptive attack. Launch-on-warning and simultaneous release of all strategic weapons are two of several ominous and destabilizing innovations contrived in response to the fear of a first strike.

The number of U.S. land-based strategic missiles is about 1,050; for the Soviet Union, about 1,400. In addition, each side has at least several dozen dedicated and alternative strategic bomber bases and airstrips, as well as command and control facilities, submarine ports and other prime strategic targets on land. Each target requires—for high probability of its destruction—two or perhaps three attacking warheads. Thus, a convincing first strike against land targets requires at least 2,200 and perhaps as many as 4,500 attacking warheads. Some—for example, to disable bombers that succeed in becoming airborne just before the first strike—would detonate as airbursts. While many missile silos, especially in the United States, are surrounded by farmland and brush, other strategic targets, especially in Europe and Asia, are sufficiently near forests or urban areas for major conflagrations to be set, even in a "pure" counterforce attack. Accordingly, a major first strike would be clearly in the vicinity of, and perhaps well over, the climatic threshold.

A counterforce first strike is unlikely to be completely effective. Perhaps 10 to 40 percent of the adversary's silos and most of its airborne bombers and submarines at sea will survive, and *its* response may not be against silos, but against cities. Ten percent of a 5,000-warhead strategic arsenal is 500 warheads: distributed over cities, this seems by itself enough to trigger a major climatic catastrophe.

Such a first strike scenario, in which the danger to the aggressor nation depends upon the unpredictable response of the attacked nation, seems risky enough. (The hope for the aggressor nation is that its retained second-strike force, including strategic submarines and unlaunched land-based missiles, will intimidate the adversary into surrender rather than provoke it into retaliation.) But the decision to launch a first strike that is tantamount to national suicide for the aggressor—*even if the attacked nation does not lift a finger to retaliate*—is a different circumstance altogether. If a first strike gains no more than a pyrrhic victory of ten days' duration before the prevailing winds carry the nuclear winter to the aggressor nation, the "attractiveness" of the first strike would seem to be diminished significantly.

A Doomsday Machine is useless if the potential adversary is ignorant of its presence.[19] But since many distinguished scientists, both American and Soviet, have participated vigorously in recent studies of the climatic consequences of nuclear war, since there appears to be no significant disagreement in the conclusions, and since policymakers will doubtless be apprised of these new results, it would appear that a decision to launch a major first strike is now much less rational, and therefore, perhaps, much less probable. The better political leaders understand the nuclear winter, the more secure are such conclusions.

If true, this should have cascading consequences for specific weapons systems. Further, the perceived vulnerability to a first strike has been a major source of stress and fear, and thereby a major spur to the nuclear arms race. Knowledge that a first strike is now less probable might make at least some small contribution to dissipating the poisonous atmosphere of mistrust that currently characterizes Soviet-American relations.

2. *Sub-threshold War.* Devastating nuclear wars that are nevertheless significantly below the threshold for severe climatic consequences certainly seem possible—for example, the destruction of 10 or 20 cities, or 100 silos of a particularly destabilizing missile system. Nevertheless, might some nation be tempted to initiate or engage in a much larger, but still reliably sub-threshold nuclear war? The hope might be that the attacked adversary would be reluctant to retaliate for fear of crossing the threshold.

This is not very different from the hope that a counterforce first strike would not be followed by a retaliatory strike, because of the aggressor's retention of an invulnerable (for example, submarine-based) second-strike force adequate to destroy populations and national economies. It suffers the same deficiency—profound uncertainty about the likely response.

The strategic forces of the United States or the Soviet Union—even if they were all at fixed sites—could not be destroyed in a reliably sub-threshold war: there are too many essential targets. Thus, a sub-threshold first strike powerfully provokes the attacked nation and leaves much of its retaliatory force untouched. It is easy to imagine a nation, having contemplated becoming the object of a sub-threshold first strike, planning to respond in kind, because it judges that failure to do so would itself invite attack. Retaliation could occur immediately against a few key cities—if national leaders were restrained and command and control facilities intact—or massively, months later, after much of the dust and smoke have fallen out, extending the duration but ameliorating the severity of the net climatic effects.

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[19] The term "Doomsday Machine" is due to Herman Kahn, *Thinking About the Unthinkable,* New York: Horizon Press, 1962.

This, however, may not be the case for such nations as Britain, France or China. Because of the marked contiguity of strategic targets and urban areas in Europe, the climatic threshold for attacks on European nuclear powers may be significantly less than for the United States or the Soviet Union. Provided it could be accomplished without triggering a U.S.-Soviet nuclear war, first strikes against all the fixed-site strategic forces of one of these nations might not trigger the climatic catastrophe. Nevertheless, the invulnerable retaliatory capability of these nations—especially the ballistic-missile submarines of Britain and France—makes such a first strike unlikely.

3. *Treaties on Yields and Targeting.* I would not include this possibility, except that it has been mentioned publicly by a leading American nuclear strategist. The proposal has two parts. The first is to ban by treaty all nuclear warheads with yields in excess of 300 or 400 kilotons. The fireballs from warheads of higher yields mainly penetrate into the stratosphere and work to deplete the ozonosphere.

The reconversion of nuclear warheads to lower individual yields would reduce (although not remove) the threat of significantly enhanced ultraviolet radiation at the surface of the Earth, but would in itself have no bearing on the issue of climatic catastrophe, and would increase the intermediate-timescale radioactive fallout. Within the present strategic arsenals, there is no mix of yields that simultaneously minimizes ionizing radiation from fallout and ultraviolet radiation from the Sun.

As delivery system accuracy has progressively improved, there has been a corresponding tendency toward the deployment of lower-yield warheads, although not through any concern about the integrity of the ozonosphere. There is also a trend toward higher fission fractions, implying more radioactive fallout. Limitations on the sizes and therefore, to some extent, on the yields of new warheads are part of recent U.S. arms control proposals. With the bulk of Soviet strategic warheads having yields larger than their U.S. counterparts, however, treaties limiting high yields place greater demands on Soviet than on U.S. compliance. Moreover, to enforce a categorical yield ceiling seems to imply verification problems of some difficulty.

The second part of the proposal is to guarantee by treaty that cities would not be targeted. Then the worst of the climatic effects might be avoided, although the climatic consequences of "pure" counterforce exchanges can still be extremely serious (Figure 1). The encoding of targeting coordinates, however, is in principle done remotely, and involves different coordinates for each warhead. Even if we could imagine international inspection teams descending unannounced on Soviet or American missile silos to inspect the targeting coordinates, an hour later the coordinates could be returned to those appropriate for cities.

Targeting policy is among the most sensitive aspects of nuclear strategy, and maintaining uncertainty about targeting policy is thought to be an essential component of U.S. deterrence. The proposal is unlikely to be received warmly by the U.S. Joint Strategic Targeting Staff or its Soviet counterpart. It is also difficult to understand how those skeptical of the verifiability by reconnaissance satellites of SALT II provisions on the deployment of missiles ten meters long can rest easy about verification of treaties controlling what is encoded in a microchip one millimeter long. Nevertheless, a symbolic, unverifiable targeting treaty, entered into because both sides recognize that it is not in their interest to target cities, might have some merit.

4. *Transition to Low-Yield High-Accuracy Arsenals.* A conceivable response to the prospect of climatic catastrophe might be to continue present trends toward lower-yield and higher-accuracy missiles, perhaps accompanied by development of the technology for warheads to burrow sub-surface before detonating. Payloads have been developed for the Pershing II missile that use radar area-correlators for target recognition and terminal guidance; the targeting probable error is said to be 40 meters.[20] It is evident that a technology is gradually emerging that could permit delivery accuracies of 35 meters or better over intercontinental ranges.

It is evident as well that burrowing technology is also under rapid development.[21] A one-kiloton burst, two to three meters sub-surface, will excavate a crater roughly 60 meters across.[22] Clearly, high-accuracy penetrating warheads in the one-to-ten-kiloton range would be able, with high reliability, to destroy even very hardened silos and underground command posts.

[20] *Aviation Week and Space Technology*, May 15, 1978, p. 225.

[21] *Ibid.*

[22] S. Glasstone and P. J. Dolan, *op. cit.* footnote 2.

Low-yield sub-surface explosions of this sort cannot threaten the ozonosphere. They minimize fires, soot, stratospheric dust and radioactive fallout. Even several thousand simultaneous such detonations might not trigger the nuclear winter. Similar technology might be used for pinpoint attacks on military/industrial targets in urban areas. Thus, the TTAPS results will probably lead to calls for further improvements in high-accuracy earth-burrowing warheads.

There are, I think, a number of difficulties with this proposal, as attractive as it seems in a strictly military context. A world in which the nuclear arsenals were completely converted to a relatively small number of burrowing low-yield warheads would be much safer in terms of the climatic catastrophe. But such warheads are provocative. They are the perfect post-TTAPS first-strike weapon. Their development might well be taken as a serious interest in making a climatically safe but disabling first strike. Greatly expanded deployment of anti-ballistic missiles might be one consequence of their buildup.

Retaliation from surviving silos, aircraft and especially submarines, as discussed above, is likely, whatever the disposition of yields in a first strike. Also, arsenals cannot be converted instantaneously. There would be a very dangerous and protracted transition period in which enough newer weapons are deployed to be destabilizing, and enough older weapons are still in place to trigger the nuclear winter.

However, if the inventories of modern higher-yield (more than ten kiloton) warheads were first brought below threshold, a coordinated U.S.-Soviet deployment of low-yield burrowers might be accomplished in somewhat greater safety. On many launchers, each with a single warhead, they might provide a useful reassurance to defense ministries at some points in the transition process. At any rate, the dramatic reduction of arsenals necessary to go below threshold before large-scale burrower deployment is indistinguishable from major arms reduction for its own sake (see below).

5. *Consequences for the Developing World:* Before the TTAPS calculations were performed, it was possible to argue that the developing world would be severely affected by secondary economic consequences, but not fundamentally destroyed by a northern mid-latitude nuclear war. Now it seems more likely that nations having no part in the conflict—even nations entirely neutral in the global confrontation between the United States and the Soviet Union—might be reduced to prehistoric population levels and economies, or worse. Nations between 70°N and 30°S, nations with marginal economies, nations with large food imports or extensive malnutri-

tion today, and nations with their own strategic targets are particularly at risk.

Thus, the very survival of nations distant from any likely nuclear conflict can now be seen to depend on the prudence and wisdom of the major nuclear powers. India, Brazil, Nigeria or Saudi Arabia could collapse in a nuclear war without a single bomb being dropped on their territories.[23]

Quite apart from any concern about the deflection of world financial, technical and intellectual resources to the nuclear arms race, the prospect of nuclear war now clearly and visibly threatens every nation and every person on the planet. The diplomatic and economic pressure accordingly placed on the five nuclear powers by the other nations of the world, concerned about their own survival, could be at least marginally significant.

6. *Shelters*. The usual sorts of shelters envisioned for civilian populations are ineffective even for the nuclear war consequences known before the TTAPS study. The more ambitious among them include food and water for a week or two, modest heating capabilities, rudimentary sanitary and air filtration facilities and no provisions for the psychological burdens of an extended stay below ground with unknown climatic and ecological consequences propagating overhead. The kinds of shelters suitable for prolonged subfreezing temperatures, high radiation doses, and pyrotoxins would have to be very much more elaborate—quite apart from the question of what good it would be to emerge six or nine months later to an ultraviolet-bathed and biologically depauperate surface, with insect pests proliferating, disease rampant, and the basis of agriculture destroyed.

Appropriate shelters, able to service individual families or family groups for months to a year, are too expensive for most families even in the affluent West. The construction of major government shelters for civilian populations would be enormously expensive as well as in itself potentially destabilizing. The prospect of the climatic catastrophe also heightens the perceived inequity between government leaders and (in some cases) their families, provided elaborate shelters, and the bulk of the civilian population, unable to afford even a minimally adequate shelter.

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[23] The distribution of the coldest regions will vary with time and geography. In one recent but still very crude three-dimensional simulation of the nuclear winter, the temperature has, by 40 days after the war, dropped by 15 to more than 40 centigrade degrees over much of the globe, including a vast region extending from Chad to Novosibirsk, from the Caspian Sea to Sri Lanka, embracing India, Pakistan and western China, and having its most severe effects in Afghanistan, Iran and Saudi Arabia. V. V. Alexandrov and G. L. Stenchikov, preprint, Computing Center, U.S.S.R. Academy of Sciences, Moscow, 1983.

But even if it were possible to build perfectly effective shelters for the entire populations of the United States and the Soviet Union, this would in no way address the danger to which the rest of the world would be put. Shelters for the combatant nations under circumstances in which only their citizens are threatened are one thing. Shelters for the combatant nations when gravely threatened noncombatant nations have only rudimentary or nonexistent shelters are a very different matter.

7. *Ballistic-Missile Defense Systems.* It might be argued that the prospect of a climatic catastrophe strengthens whatever arguments there may be for ground-based or space-based ballistic missile defense (BMD) systems, as proposed by President Reagan in his March 23, 1983 "Star Wars" speech. There are grave technical, cost and policy difficulties with such proposals.[24] Even advocates do not envision it being fully operational in less than two or three decades.

Optimistic informed estimates of porosity or "penetrance" (the fraction of attacking missiles successfully detonating at their targets despite the BMD) are no lower than 5 to 30 percent. The present world arsenal of strategic warheads is so much greater than the threshold for climatic catastrophe that, even if 5 to 30 percent of attacking missiles get through in something like a full exchange, the catastrophe could be triggered. And most competent estimates put the porosity—at least for the foreseeable future—at 50 percent to 99 percent. Further, one likely response to an adversary's anticipated deployment of BMD systems would be a proportionate increase in the stockpiles of offensive warheads in compensation.

There are three phases in the trajectories of incoming missiles when they might be attacked: boost phase, midcourse phase, and terminal phase. Boost-phase and midcourse interception would, at best, require an untried technology deployed at scales never before attempted. Only terminal-phase BMDs exist at the present time (antiballistic missiles or ABMs), and even they, ineffective as they are, may require ruinous capital investments before they can provide meaningful levels of defense. Developments in terminal-phase maneuverability of attacking warheads are likely to raise the price tag of an effective BMD sharply again. Even in the best of circumstances, offense will be more effective and less costly than defense.

Finally, terminal-phase interception, generally effective only for hard-target defense, is characteristically designed to occur at very low altitudes. There would be an advantage to the offense if it fused the incoming missiles so they would explode if attacked ("sympathetic detonation"). In some schemes, the BMD itself involves nuclear warheads exploded near the ground. A fair fraction of hard targets, especially in Europe and the Soviet Union, are within a few tens of kilometers of cities or forests. Thus, the most readily deployable BMD suffers the disability, when it works at all, of generating fires contributory to a climatic catastrophe, quite apart from its porosity.

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[24] Richard Garwin, testimony before the Subcommittee on International Security and Scientific Affairs of the House Committee on Foreign Affairs, U.S. Congress, November 10. 1983; Hans Bethe, manuscript in preparation.

8. *Other Possibilities.* There are a number of other conceivable responses to the climatic catastrophe, some even more desperate than those discussed above. For example, a nation might relocate its silos and mobile launchers (the latter inviting barrage attack) to cities and forests to guarantee that a barely adequate counterforce first strike by its adversary would trigger a global climatic catastrophe with high confidence. Or nations with small nuclear arsenals or marginal strategic capability might contemplate amassing a threshold arsenal of some 500 to 2,000 deliverable warheads in order to be taken seriously in "great power" politics.

But these and similar contrivances increase the probability of nuclear war or the dangers attendant to nuclear war sufficiently that they are likely to be rejected by the nation contemplating such moves or, failing that, by other nations. Major relocations of strategic weapons systems or the deployment of new strategic arsenals are readily detectable by national technical means.

V

None of the foregoing possible strategic and policy responses to the prospect of a nuclear war-triggered climatic catastrophe seem adequate even for the security of the nuclear powers, much less for the rest of the world. The prospect reinforces, in the short run, the standard arguments for strategic confidence-building, especially between the United States and the Soviet Union; for tempering puerile rhetoric; for resisting the temptation to demonize the adversary; for reducing the likelihood of strategic confrontations arising from accident or miscalculation; for stabilizing old and new weapons systems—for example, by de-MIRVing missiles; for abandoning nuclear-war-fighting strategies and mistrusting the possibility of "containment" of a tactical or limited nuclear war; for considering safe unilateral steps, such as the retiring of some old weapons systems with very high-yield warheads; for improving communications at all levels, especially among general staffs and between heads of governments; and for public declarations of relevant policy changes. The United States might also contemplate ratification of SALT II and of the 1948 U.N. Convention on the Prevention and Punishment of the Crime of Genocide (ratified by 92 nations, including the Soviet Union).

Both nations might consider abandoning apocalyptic threats and doctrines. To the extent that these are not credible, they undermine deterrence; to the extent that they are credible, they set in motion events that tend toward apocalyptic conclusions.

In the long run, the prospect of climatic catastrophe raises real questions about what is meant by national and international security. To me, it seems clear that the species is in grave danger at least until the world arsenals are reduced below the threshold for climatic catastrophe; the nations and the global civilization would remain vulnerable even at lower inventories. It may even be that, now, the only credible arsenal is below threshold. George Kennan's celebrated proposal[25] to reduce the world arsenals initially to 50 percent of their current numbers is recognized as hard enough to implement. But it would be only the first step toward what is now clearly and urgently needed—a more than 90-percent reduction (Kennan proposed an ultimate reduction of more than 84 percent—adequate for strategic deterrence, if that is considered essential, but unlikely to trigger the nuclear winter. Still further reductions could then be contemplated.

The detonation of weapons stockpiles near or above threshold would be, we can now recognize, in contravention of the 1977 Geneva Convention on The Hostile Use of Environmental Modification Techniques, signed by 48 nations and duly ratified by the Soviet Union and the United States.[26] And Article 6 of the 1968 Nuclear Non-Proliferation Treaty requires the United States and the Soviet Union, among other signatory states, "to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament. . . ." I do not imagine that these treaties can, by themselves, play a determining role in producing major reductions in the world strategic arsenals, but they establish some sense of international obligation and can at least expedite urgent bilateral and multilateral consultations.

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[25] George F. Kennan, "The Only Way Out of the Nuclear Nightmare," *Manchester Guardian Weekly*, May 31, 1981. This is Kennan's acceptance speech for the Albert Einstein Peace Prize on May 19, 1981, in Washington, D.C.

[26] Article 1, paragraph 1, states: "Each State Party to this Convention undertakes not to engage in military or any other hostile use of environmental modification techniques having widespread, long-lasting or severe effects as the means of destruction, damage, or injury to another State Party." Paragraph 2 goes on: "Each State Party to this Convention undertakes not to assist, encourage or induce any State, group of States or international organization to engage in activities contrary to the provisions of paragraph 1 . . ."

VI

We have, by slow and imperceptible steps, been constructing a Doomsday Machine. Until recently—and then, only by accident—no one even noticed. And we have distributed its triggers all over the Northern Hemisphere. Every American and Soviet leader since 1945 has made critical decisions regarding nuclear war in total ignorance of the climatic catastrophe. Perhaps this knowledge would have moderated the subsequent course of world events and, especially, the nuclear arms race. Today, at least, we have no excuse for failing to factor the catastrophe into long-term decisions on strategic policy.

Since it is the soot produced by urban fires that is the most sensitive trigger of the climatic catastrophe, and since such fires can be ignited even by low-yield strategic weapons, it appears that the most critical ready index of the world nuclear arsenals, in terms of climatic change, may be the total *number* of strategic warheads. (There is some dependence on yield, to be sure, and future very low-yield, high-accuracy burrowing warheads could destroy strategic targets without triggering the nuclear winter, as discussed above.) For other purposes there are other indices—numbers of submarine-launched warheads, throw-weight (net payload deliverable to target), total megatonnage, etc. From different choices of such indices, different conclusions about strategic parity can be drawn. In the total number of strategic warheads, however, the United States is "ahead" of the Soviet Union and always has been.

Very roughly, the level of the world strategic arsenals necessary to induce the climatic catastrophe seems to be somewhere around 500 to 2,000 warheads—an estimate that may be somewhat high for airbursts over cities, and somewhat low for high-yield groundbursts. The intrinsic uncertainty in this number is itself of strategic importance, and prudent policy would assume a value below the low end of the plausible range.

National or global inventories above this rough threshold move the world arsenals into a region that might be called the "Doomsday Zone." If the world arsenals were well below this rough threshold, no concatenation of computer malfunction, carelessness, unauthorized acts, communications failure, miscalculation and madness in high office could unleash the nuclear winter. When global arsenals are above the threshold, such a catastrophe is at least possible. The further above threshold we are, the more likely it is that a major exchange would trigger the climatic catastrophe.

Traditional belief and childhood experience teach that more weapons buy more security. But since the advent of nuclear weapons and the acquisition of a capacity for "overkill," the possibility has arisen that, past a certain point, more nuclear weapons do not increase national security. I wish here to suggest that, beyond the climatic threshold, an increase in the number of strategic weapons leads to a pronounced *decline* in national (and global) security. National security is not a zero-sum game. Strategic insecurity of one adversary almost always means strategic insecurity for the other. Conventional pre-1945 wisdom, no matter how deeply felt, is not an adequate guide in an age of apocalyptic weapons.

If we are content with world inventories above the threshold, we are saying that it is safe to trust the fate of our global civilization and perhaps our species to all leaders, civilian and military, of all present and future major nuclear powers; and to the command and control efficiency and technical reliability in those nations now and in the indefinite future. For myself, I would far rather have a world in which the climatic catastrophe cannot happen, independent of the vicissitudes of leaders, institutions and machines. This seems to me elementary planetary hygiene, as well as elementary patriotism.

Something like a thousand warheads (or a few hundred megatons) is of the same order as the arsenals that were publicly announced in the 1950s and 1960s as an unmistakable strategic deterrent, and as sufficient to destroy either the United States or the Soviet Union "irrecoverably." Considerably smaller arsenals would, with present improvements in accuracy and reliability, probably suffice. Thus it is possible to contemplate a world in which the global strategic arsenals are below threshold, where mutual deterrence is in effect to discourage the use of those surviving warheads, and where, in the unhappy event that some warheads are detonated, there is little likelihood of the climatic catastrophe.[27]

To achieve so dramatic a decline in the global arsenals will require not only heroic measures by both the United States and the Soviet Union—it will also require consistent action by Britain, France and China, especially when the U.S. and Soviet arsenals are significantly reduced. Currently proposed increments in the arsenals at least of France would bring that nation's warhead inventory near or above threshold. I have already remarked on the strategic instability, in

[27] Since higher-yield tactical warheads can also be used to burn cities, and might do so inadvertently, especially in Europe, provision for their elimination should also eventually be made. But initial attention should be directed to strategic warheads and their delivery systems.

the context of the climatic catastrophe only, of the warhead inventories of these nations. But if major cuts in the U.S. and Soviet arsenals were under way, it is not too much to hope that the other major powers would, after negotiations, follow suit. These considerations also underscore the danger of nuclear weapons proliferation to other nations, especially when the major inventories are in steep decline.

Figure 2, on the following page, illustrates the growth of the American and Soviet strategic inventories from 1945 to the present.[28] To minimize confusion in the Figure, the British, French and Chinese arsenals are not shown; they are, however, as just mentioned, significant on the new scale of climatically dangerous arsenals. We see from the Figure that the United States passed the Doomsday Threshold around 1953, and the Soviet Union not until about 1966. The largest disparity in the arsenals was in 1961 (a difference of some 6,000 warheads). At the present time the disparity is less than it has been in any year since 1955. A published extrapolation of the present strategic arsenals into 1985 is shown as dashed, nearly vertical lines, accommodating new U.S. (Pershing II, cruise, MX and Trident) and Soviet (SS-21, -22, -23) strategic systems. If these extrapolations are valid, the United States and the Soviet Union would have almost identical numbers of inventories by the late 1980s.

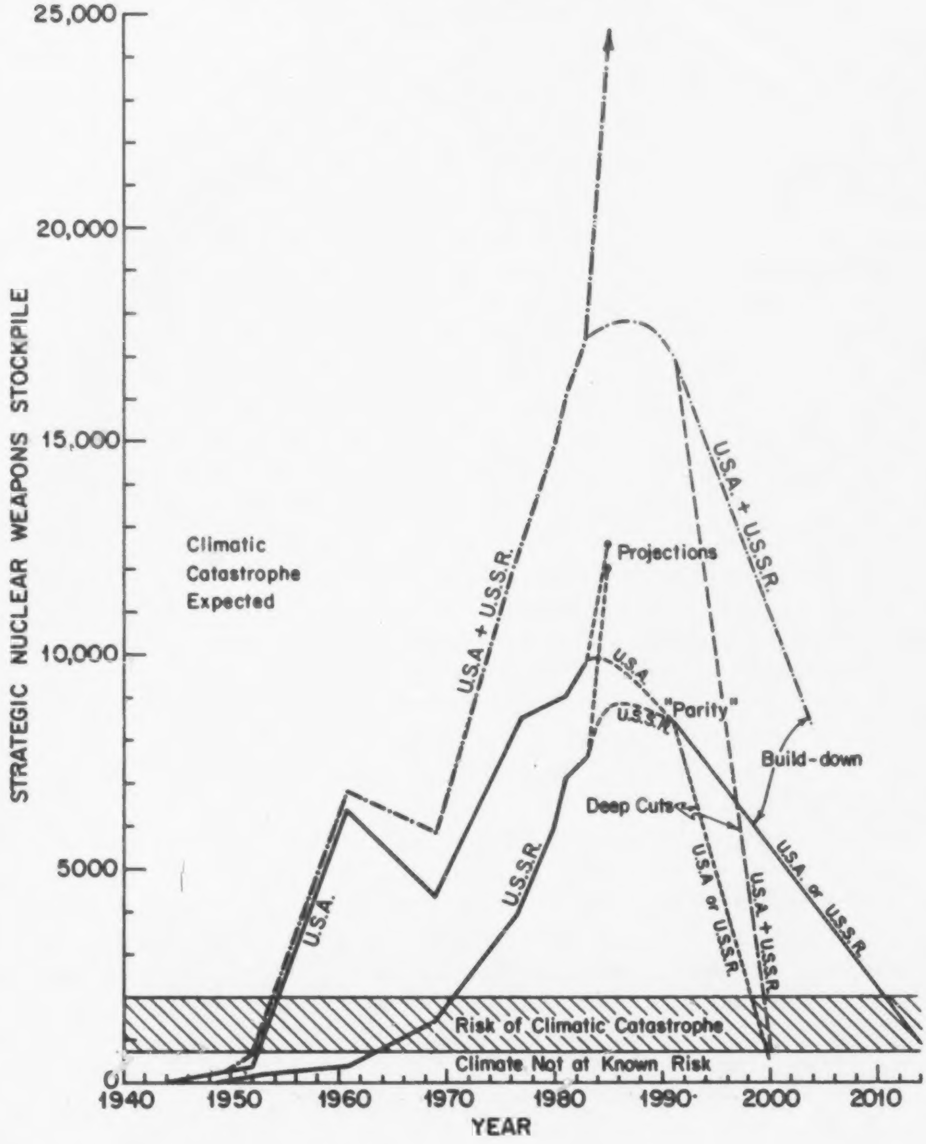
The uppermost (dash-dot) curve in Figure 2 shows the total U.S. and Soviet arsenals (essentially the world arsenals) climbing upward since about 1970 with a very steep slope, the slope steepening still more if the projection is valid. Such exponential or near-exponential runaways are expected in arms races where each side's rate of growth is proportional to its perception of the adversary's weapons inventory; but it is likewise clear that such rapid growth cannot

[28] The total warheads calculated in Figure 2 include strategic and theater weapons, but not tactical weapons. Not all published sources are in perfect agreement on these numbers. The principal sources used here are the *Report of the Secretary of Defense [Harold Brown] to the Congress on the FY 1982 Budget, FY 1983 Authorization Request* and *FY 1986 Defense Programs*, Washington: Department of Defense, 1981; and *National Defense Budget Estimates, FY 1983*, Office of the Assistant Secretary of Defense, Comptroller, March 1982.

Beyond 1983, projected increases in arsenals are shown for U.S. and Soviet arsenals as nearly vertical dashed lines, with the sum of these arsenals as the line at the top of the Figure terminating in an arrowhead. The data are from Frank Barnaby in the special issue of *Ambio* cited in footnote 5, pp. 76–83. See also *Counterforce Issues for the U.S. Strategic Nuclear Forces*, Congressional Budget Office, January 1978.

Figure 2 shows three regions: an upper region in which the nuclear winter could almost certainly be triggered; a lower region at which it could not be triggered; and a transition zone, shown shaded. The boundaries of this transition zone are more uncertain than shown, and depend among other things on targeting strategy. But the threshold probably lies between several hundred and a few thousand contempory strategic weapons.

FIGURE 2
PAST AND FUTURE NUCLEAR STOCKPILES



continue indefinitely. In all natural and human systems, such steep growth rates are eventually stopped, often catastrophically.

It is widely agreed—although different people have different justifications for this conclusion—that world arsenals must be reduced significantly. There is also general agreement, with a few demurrers, that at least the early and middle stages of a significant decline can be verified by national technical means and other procedures. The first stage of major arms reduction will have to overcome a new source of reluctance, when almost all silos could be reliably destroyed in a sub-threshold first strike. To overcome this reluctance, both sides will have prudently maintained an invulnerable retaliatory force, which itself would later move to subthreshold levels. (It would even be advantageous to each nation to provide certain assistance in the development of such a force by the other.)

As arsenals are reduced still further, the fine tuning of the continuing decline may have to be worked out very carefully and with additional safeguards to guarantee continuing rough strategic parity. As threshold inventories are approached, some verifiable upper limits on yields as well as numbers would have to be worked out, to minimize the burning of cities if a nuclear conflict erupted. On the other hand, the deceleration of the arms race would have an inertia of its own, as the acceleration does; and successful first steps would create a climate conducive to subsequent steps.

There are three proposals now prominently discussed in the United States: Nuclear Freeze, Build-Down, and Deep Cuts. Their possible effects are diagrammed in Figure 2. They are by no means mutually exclusive, nor do they exhaust the possible approaches. A negotiated Freeze would at least prevent the continuing upward escalation in stockpiles, would forestall the deployment of more destabilizing systems, and would probably be accompanied by agreement on immediate annual phased reductions (the curved lines in the middle to late 1980s in Figure 2). To reduce the perceived temptation for a first strike, de-MIRVing of missiles during arms reduction may be essential.

The most commonly cited method of following the Freeze with reductions is incorporated in the Kennedy-Hatfield Freeze Resolution: percentage reductions. Under this approach, the two sides would agree on a percentage—often quoted as being between five percent and ten percent—and would agree to decrease deployed warheads by that percentage annually. The percentage reduction method was proposed to the Soviet Union by the United States at the Vienna Summit in June 1979 and was to be applied to the limits and sub-limits of the SALT II accords until these reached a reduction of 50 percent.

The Build-Down proposal is one in which modernization is permitted, but each side must pay a price in additional reductions of warheads for each warhead mounted on a modernized missile. In many current versions of the proposal, it would also require both sides to decrease their total warhead inventories by about five percent a year (again, the percentage annual reduction approach), to ensure that at least some reductions would take place even if modernization did not. The rate of decline for Build-Down illustrated in Figure 2 is essentially that of Representative Albert Gore (D.-Tenn.), in which rough parity at 8,500 warheads each is adopted as a goal for 1991–92, and the levels are reduced to 6,500 warheads each by 1997.[29]

There is concern that the "modernization" of strategic systems that Build-Down encourages might open the door to still more destabilizing weapons. It is also by no means clear that all proponents of Build-Down envision further reductions below the interim goal of about 5,000 warheads each for the United States and Soviet Union. If this rate of Build-Down continued indefinitely, the two nations would not cross back below threshold until about the year 2020. As dramatic a change from the present circumstances as this represents, in light of the present global crisis, it is, I think, too leisurely a pace.

Deep Cuts, originally advocated by George Kennan and Noel Gayler[30] as an initial halving of the global arsenals in some relatively short period of time, proposes the turning in of the fission triggers of thermonuclear weapons, deployed or undeployed, to a binational or multinational authority, with the triggers subsequently gainfully consumed in nuclear power plants (the ultimate in beating swords into plowshares). A highly schematic curve for something like Deep Cuts is also shown in Figure 2, starting from Gore's assumption of parity by 1991–92. Halving of the present global arsenals would then occur around 1995, and the global arsenals would return to below the Doomsday Threshold by the year 2000.

The actual shape of these declining curves would very likely have kinks and wiggles in them to accommodate the details of a bilaterally—and eventually multilaterally—agreed-upon plan to reduce the arsenals without compromising the security of any of the nuclear powers. The Deep Cuts curve shown has a rate of decline only about as steep as the rate of rise beginning in 1970. Much steeper declines may be feasible and should be considered.

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[29] *Congressional Record*, August 4, 1983, Vol. 129, No. 114.

[30] George F. Kennan, *loc. cit.* footnote 24; Noel Gayler, "How to Break the Momentum of the Nuclear Arms Race," *The New York Times Magazine*, April 25, 1982.

No one contends it will be easy to reverse the nuclear arms race. It is required at least for the same reasons that were used to justify the arms race in the first place—the national security of the United States and the Soviet Union. It is necessarily an enterprise of great magnitude. John Stuart Mill said: "Against a great evil, a small remedy does not produce a small result. It produces no result at all." But if the same technical ingenuity, dedication and resources were devoted to the downward slopes in Figure 2 as to the upward slopes, there is no reason to doubt that it could be negotiated safely. In the deployment of more stabilizing weapons systems, in the possible development—especially in later stages of arms reductions—of novel means of treaty verification, and (perhaps) in the augmentation of conventional armaments, it will, of course, be expensive.

But, given the stakes, a prudent nuclear power should be willing to spend more every year to defuse the arms race and prevent nuclear war than it does on all military preparedness. For comparison, in the United States the annual budget of the Department of Defense is about 10,000 times that of the Arms Control and Disarmament Agency, quite apart from any questions about the dedication and effectiveness of the ACDA. The equivalent disparity is even greater in many other nations. I believe that the technical side of guaranteeing a major multilateral and strategically secure global arms reduction can be devised and deployed for considerably less—perhaps even a factor of 100 less—than the planet's direct military expenditures of $540 billion per year.[31]

Such figures give some feeling for the chasm that separates a prudent policy in face of our present knowledge of nuclear war from the actual present policies of the nuclear powers. Likewise, nations far removed from the conflict, even nations with little or no investment in the quarrels among the nuclear powers, stand to be destroyed in a nuclear war, rather than benefiting from the mutual annihilation of the superpowers.. They too, one might think, would be wise to devote considerable resources to help ensure that nuclear war does not break out.

VII

In summary, cold, dark, radioactivity, pyrotoxins and ultraviolet light following a nuclear war—including some scenarios involving only a small fraction of the world strategic arsenals—would imperil every survivor on the planet. There is a real danger of the extinction of humanity. A threshold exists at which the climatic catastrophe could be triggered, very roughly around 500–2,000 strategic warheads. A major first strike may be an act of national suicide, even if no retaliation occurs. Given the magnitude of the potential loss, no policy declarations and no mechanical safeguards can adequately guarantee the safety of the human species. No national rivalry or ideological confrontation justifies putting the species at risk. Accordingly, there is a critical need for safe and verifiable reductions of the world strategic inventories to below threshold. At such levels, still adequate for deterrence, at least the worst could not happen should a nuclear war break out.

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[31] Ruth Leger Sivard, *World Military and Social Expenditures*, Leesburg (Va.): World Priorities, 1983.

National security policies that seem prudent or even successful during a term of office or a tour of duty may work to endanger national—and global—security over longer periods of time. In many respects it is just such short-term thinking that is responsible for the present world crisis. The looming prospect of the climatic catastrophe makes short-term thinking even more dangerous. The past has been the enemy of the present, and the present the enemy of the future.

The problem cries out for an ecumenical perspective that rises above cant, doctrine and mutual recrimination, however apparently justified, and that at least partly transcends parochial fealties in time and space. What is urgently required is a coherent, mutually agreed upon, long-term policy for dramatic reductions in nuclear armaments, and a deep commitment, embracing decades, to carry it out.

Our talent, while imperfect, to foresee the future consequences of our present actions and to change our course appropriately is a hallmark of the human species, and one of the chief reasons for our success over the past million years. Our future depends entirely on how quickly and how broadly we can refine this talent. We should plan for and cherish our fragile world as we do our children and our grandchildren: there will be no other place for them to live. It is nowhere ordained that we must remain in bondage to nuclear weapons.

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On minimizing the consequences of nuclear war

from Carl Sagan

The likely long-term global consequences of nuclear war remain catastrophic, despite attempts to minimize the dangers.

A FULL-SCALE nuclear war would be an unprecedented human catastrophe. But because we have no direct experience of such a war, the consequences and the policy implications must to some extent be uncertain. After an initial indication that soot from nuclear fires might provide significant atmospheric opacity[1], recent calculations (refs 2, 3 and subsequent investigations) have shown that the soot and dust attendant on nuclear war could, under many contingencies, cool and darken the Earth, with devastating global biological consequences[4]. This climatic catastrophe is called nuclear winter.

We believe our calculations[2,3] to be a valid first-order assessment, although further research is needed to reduce uncertainties. We know of no factors that significantly and reliably reduce the possibility of grave worldwide climatic effects after a large-scale nuclear war. A survey by the US National Academy of Sciences[5] concludes that there is a "clear possibility" both of "severe" consequences and of effects "that would be greater than, and would last longer than, that estimated in the baseline case". It is also possible that uncertainties might ameliorate the baseline climatic catastrophe. A study, by a committee appointed by the Royal Society of Canada[46], concludes "we believe nuclear winter to be a formidable threat" and its analyses "tend to confirm that a drastic cooling will occur in the wake of a major nuclear war". An extensive analysis by a committee of the International Council of Scientific Unions[49] concludes "There is a considerable probability a major nuclear war could gravely disrupt the global environment and world society."

Because these results and their implications for policy and doctrine[6] are at considerable variance with the prevailing wisdom, it is natural and healthy that competent criticism be aired. However, in parallel with an inclination in the popular literature to exaggerate the consequences of nuclear war, there has also been a tendency in many professional pronouncements to down-play the consequences, a tendency which has been noted (and not only with respect to nuclear war) in the risk-assessment literature[45].

In a recent *Nature* article[7], in *The Reader's Digest*[8] and in testimony before the Committee on Science and Technology of the US House of Representatives[9], Edward Teller has demonstrated a dangerous propensity to minimize or ignore the consequences of nuclear war. He concludes that radioactive fallout, depletion of the protective ozone layer, and nuclear winter following a major nuclear war have all been "exaggerated". He artificially divides the total problem into small pieces, and then pronounces each piece "manageable".

Fallout

Teller concludes that fallout is "far less important than originally feared". Unaccountably he does not deal with the prompt fallout that would contaminate large areas of the target zones and adjacent territory in a nuclear war, eventually causing at least tens of millions of civilian fatalities[10]. In a major nuclear war, 30 per cent of Northern mid-latitude land areas, where the majority of people live, could receive fallout burdens approaching or exceeding the acute mean lethal dose for unprotected populations[2,3]. By any standard, such effects would seem worthy of note.

On an intermediate timescale, still more widespread radioactive fallout would, over the years, cause further millions of cases of cancer and birth defects among the survivors of a nuclear war[11] and would produce serious effects synergistic with other consequences of nuclear war[4]. Teller says that the "best current calculations" from the Livermore weapons laboratory[12] indicate average long-term mid-latitude doses of about 20 rem, provided nuclear reactors, fuel reprocessing plants and spent fuel storage facilities are not targeted. But these calculations (still unpublished in a refereed journal) are based on relatively simple empirical scaling from nuclear test explosions, few of which were of a yield, or in a location, corresponding to a realistic war situation.

We independently[2,3] used a microphysical model to predict likely radiation doses two to three times larger than did the Livermore study, with the same exclusion of nuclear power facilities. Neither model is entirely suited to this problem, but we must at least consider that the plausible range of such average long-term doses is 20 to 50 rem, at least an order of magnitude greater than the conventional wisdom, from which Teller did not, until recently, dissent. Both calculations also assume a fission yield fraction of 0.5, when smaller modern warheads may have fission yield fractions closer to 1.0.

Considering the other multiplicative factors quoted by Teller and by us[2,3] (for 'hotspots' and concurrent internal doses), plus the computational factors mentioned, which increase the dose range by factors of 2.5 to 5, it seems clear that long-term radiation exposure could be much more serious than Teller assumes. The radiation dose would be still larger if more than 5,000 MT were detonated (more than twice this yield exists in the current strategic arsenals) or if nuclear fuel processing and storage sites were attacked, which is not unlikely in a major nuclear war.

When delivered acute whole-body doses exceed about 100 rem, the human immune system begins to be compromised; when coupled with other assaults on people and their environment occasioned by nuclear warfare, such doses can have extremely serious implications[4]. Nevertheless, prompt radioactive fallout, in almost every case, presents the more serious threat to mid-latitude populations. But fallout on an intermediate timescale could produce serious, unpredictable and continuing morbidity worldwide and for generations to come.

It is thus simply untrue that fallout is "far less important than originally feared". Fallout, not taken properly into account when nuclear weapons were first designed, began to be studied seriously only after the Bravo test of the Castle series at Bikini on 1 March 1954, which accidentally contaminated (with doses in excess of 100 rem) the atoll of Rongelap in the Marshall Islands, and the Japanese fishing vessel *The Lucky Dragon.* Although some work on fallout was done as early as the Trinity Test in 1945[14], not until Castle Bravo was there extensive public discussion of the issue, eventually contributing to the 1963 Limited Test Ban Treaty.

Ozonosphere depletion

On the effects of nuclear explosions on the ozone layer, it is misleading merely to compare the widespread systematic decreases in ozone caused by massive NO_x injections in a nuclear war with the natural fluctuations and latitudinal variations observed in the ambient ozone layer. Such fluctuations would be superimposed on a decrease by several tens of per cent caused by a large nuclear war.[3] Here, as in other long-term consequences of nuclear war, it is important to distinguish between mean values and maximum excursions, both in time and in space. After a major nuclear war, average ultraviolet-B intensity would be increased above background by several factors for years, almost everywhere[2,3] Ecosystems are generally adapted to local ultraviolet fluxes, and serious damage can result from a sudden increase in exposure on this scale[15].

Teller states that there are comparatively few nuclear weapons of yield sufficient to lift NO_x high enough to cause ozone depletion. At mid-latitudes, the fireball from a 100 KT explosion will just penetrate the lower stratosphere. Most strategic warheads deployed and planned by both nuclear alliances have warheads exceeding 100 KT and, especially when gravity bombs are included, span the rough yield range from 100 KT to 1 MT (with some older weapons ranging an order of magnitude higher and some submarine-launched ballistic missile warheads a factor ≈ 2 lower)[16,17]. Teller overlooks the reinforcing effects of multiple nuclear explosions (such as from two or three bursts in rapid succession over one missile silo, with perhaps 100–200 MT detonated over a silo complex) in propelling nuclear debris to high altitudes, and the possibility of large-scale firestorm injection into the stratosphere. For these reasons, the present and future potential for ozonosphere depletion must continue to be monitored as an important secondary effect of nuclear weapons. It is noteworthy that the threat to the ozonosphere from nuclear weapons was first publicly identified not by those working on the development of nuclear weapons but by those studying an apparently unrelated problem, the effluents from proposed supersonic transport aircraft[18].

Dust

Teller invokes a still classified Livermore report, with no designation number, on the climatic effects of dust. Perhaps the report alluded to is an early analysis of the dust mass in nuclear clouds from test explosions, recently released by the cited authors as an informal and unclassified Livermore publication[19] (and which does not mention climatic effects at all).

Teller told the US House of Representatives committee[9] that, after assuming the directorship of the Lawrence Livermore National Laboratory in 1958, and after having been "troubled" by the possible climatic effects of dust "for decades before the publication of the . . . report" (ref. 3), he initiated an early computer study: "Without that, . . . all this discussion could not have taken place." In fact, none of the recent studies, and certainly none of our results, arise from these investigations, once again unpublished in refereed scientific journals. That during this period the US government was ignorant of the climatic consequences of nuclear war is made clear by the manner in which this topic is overlooked in the official study "*An assessment of frequently neglected effects of nuclear attacks*" prepared in 1978 and recently declassified[20]. Moreover, there is no record of Teller having spoken publicly about such climatic effects before 1982.

Teller's assertions that "dust raised by a large-scale war is comparable with that produced in the largest volcanic eruptions" and that the "most probable conclusion is that the . . . effects of dust would be noticeable but by no means severe on a hemispheric scale" have no quantitative foundation, and fly in the face of contrary evidence. Again, Teller divorces dust effects from all other simultaneous effects. Even isolated volcanic eruptions have been associated with striking weather anomalies, crop failures and significant human suffering. Through changes in the planetary albedo and general circulation, dust can have major climatic consequences[2,3].

Tests with chemical explosives are not a reliable basis for nuclear dust calculations. Unlike their chemical counterparts, nuclear explosions attain such great temperatures and pressures that vaporized and melted surface material contributes in a major way to the generation of fine dust particles (smaller than several micrometres in radius), and the steep thermal gradients can produce effects (such as 'popcorning') essentially unknown in chemical explosions. Tests of high explosives may, however, tell us something about the ejecta and sweep-up components of dust clouds, and place lower limits on these components in nuclear explosions. Multi-burst phenomena are also likely to augment dust production and injection heights over those expected from individual non-interacting explosions.

Smoke

Descriptions of severe climatic effects caused by smoke and dust in a nuclear war are based on detailed energy-balance calculations, including a parametric treatment of important three-dimensional processes. In our calculations, we did not 'assume' large smoke emissions, but calculated them using data from the fire and civil defence literature. We selected the most probable values of key input parameters and considered likely variations of each parameter from that choice. Generally speaking, our climatic results, for almost fifty different cases, fall within a broad range of plausible outcomes that vary from significant to grave. The results remain within this range as key physical parameters describing dust and smoke production and their properties are varied over their intervals of uncertainty. In this sense, the results can be described as 'robust' (we do not insist on the term), although not 'conclusive' or 'proved'. Compared with our predictions, including our allowances for the thermal inertia of the oceans, the actual after-effects of a full-scale nuclear war are as likely to be more as less severe. Moreover, even small-scale nuclear wars may produce major climatic effects, on at least hemispheric scales, provided cities are targeted[2,3]. Wind transport of dense smoke patches and streamers can produce "quick freezes" in distant localities very soon after the explosions[21].

To mitigate nuclear winter, Teller seems to be invoking a meteorological miracle, involving various speculative 'abnormal mechanisms'. He mentions the importance of the water vapour budget of the atmosphere. But we explicitly accounted for water cycling and scavenging by precipitation in our calculations of smoke lifetime, employing the conservative assumption that smoke is efficiently scavenged, which may not be true. Up to 50 per cent of all smoke was taken to be removed in immediate black rain. There is therefore no evidence that the water issue raised by Teller is more important than already allowed for in our calculations.

Capping clouds. One of Teller's arguments is that capping clouds will form above large fires, accelerating smoke removal. But such clouds do not occur over all fires; their occurrence depends on the local meteorology. It is not even clear that smoke particles contained in a capping cloud are removed from the atmosphere; micrometre-sized cloud particles are different from millimetre-sized precipitation particles. L. Radke observed a capping cloud over a prescribed forest burn in 1978[5], and by good chance measured the smoke properties in two dissimilar air parcels within the plume: one parcel had passed through the capping cloud, the other had not. In the cloud-processed smoke, the concentration of the smallest particles, ≤ 0.05 μm radius, was less by a factor of about 10 than in the free-drifting smoke, but the total smoke mass was comparable in both parcels. The larger particles were similar in number, and the measured optical scattering coefficients were essentially indistinguishable. In other words the processed and unprocessed smokes would have nearly equal climatic impact. (The Stokes-Cunningham fall velocities of these smoke particles are entirely negligible.) Downwind of wild-fires, the submicrometre smoke particle size distributions are usually very similar[22,23], which further suggests that cloud processing is not significant in the average case.

Washout in storms. We made separate climate calculations for ocean and land environments, using knowledge of ocean/continent wind patterns and the normal climate to estimate the ameliorating effects of the oceans on land temperatures[2,3]. Thus, while we did not perform a three-dimensional calculation, the mean effects of oceans were approximately included "in a quantitative manner". Our estimates were later supported by Livermore[24], NCAR[21,26,47], Los Alamos[48] and Soviet[25,26] two- and three-dimensional calculations for similar conditions. (The important Livermore calculations unfortunately remain unpublished in refereed journals.) The ameliorating effect of oceanic temperature must, of course, be limited; otherwise natural winters would not occur every year. While storms at ocean/continent margins would remove some of the lower-level smoke, they would also carry some to higher altitudes. Further work is needed on initial and subsequent removal rates and on the height of the stabilized smoke cloud.

Teller's speculation that smoke removal might be self-accelerating is unsound. Satellite photographs of fire plumes[27] typically show smooth and rapid dispersion over many hundreds of kilometres, with no indication of induced turbulence and washout. Furthermore, enhanced spreading and stabilization of dark oil fire plumes have been observed[28].

Smoke nucleation. The nucleating ability of smoke particles depends on their origin. In forest fires, where induced winds are expected to lift quantities of ash, char and soil debris, a substantial fraction of the particles (around 10 per cent) may act as water condensation nuclei[29]. However, in an oil fire plume without extraneous contaminating particle sources, there appears to be no significant increase of nuclei concentration over background[30]. There is also substantial observational evidence that fire plumes do not enhance, and may indeed suppress, rain formation in cane field fires[31], forest fires[29] and oil fires[30].

The origins of the black rains at Hiroshima and Nagasaki have not been unambiguously determined, although the phenomenon is clearly related to the large fires. Recent fire plume simulations based on detailed cloud physics models[32] suggest that smoke rainout may not be as frequent or as efficient as has been inferred from the anecdotal accounts at Hiroshima, or as was assumed in our calculations. A range of recent studies, presented at a Defense Nuclear Agency Conference on Large-Scale Fire Phenomenology (National Bureau of Standards, 10–13 September 1984), suggests that intense urban firestorms can propel tens of per cent of fine soot particles to high altitudes. (See also ref. 32.) Solar radiative heating of low-altitude soot can also propel it to even higher altitudes, where the residence time is approximately one year, and the coverage can rapidly become global.[3,48] These are additional respects in which the calculations in ref. 3 may be conservative.

Teller's mechanism for smoke removal depends on at least two unsupported contentions:

(1) that turbulent coastal weather can wash out a significant fraction of nuclear smoke before it can be widely dispersed; and

(2) that smoke clouds tend to become more patchy, not less, as they disperse through the atmosphere, which is contradicted by direct observations of pollutant tracers.

Urban smoke estimates. Broyles[33], the Livermore consultant whose estimates of urban smoke emission are cited by Teller, relies heavily on forest fire data, and does not review the urban fire literature or discuss smoke emissions characteristic of urban materials and conflagrations. Thus "proper modifications" for the urban case have not all been made. For example, Broyles, in his analysis, adopts smoke emission factors ranging from 0.1 per cent to 6.3 per cent, but the lower value is clearly inapplicable to cities, with their fossil fuel stocks and plastics. Accordingly, it is likely that Broyles' lower limit to smoke emission of 15 Tg (incidentally, not a strict limit) greatly understates the problem. However, even 10 Tg of sooty smoke, uniformly distributed, could decrease the average amount of sunlight reaching the Earth by one-third. Moreover, because of the necessarily uneven burning and restricted ventilation of large fires, more smoke than expected may be produced; experimental data show that restricted air flow greatly increases smoke generation[34].

Assessments of the quantities of "fuels" available in urban areas have been made by several groups[3,35,36]. These assessments are all in general agreement, although more detailed information is clearly needed. Teller notes that 150 Tg of "fuel" is available at US oil refineries[37]. However—including refineries throughout North America, the Soviet Union, Europe and the Middle East, as well as fuels in storage at transit nodes in urban areas, processed flammables in tankage, warehouses and transport, and such end products in use as roofing, paving and plastics—the actual figure for available fossil fuels and products seems to be ten times Teller's figure, or some 1,500 Tg (refs 5, 36). US strategic oil reserves in underground salt domes amount to about 80 Tg (the reserves are currently about one-half full). In some cases, the oil is close enough to the surface to pool and burn within a weapons-generated crater[38].

While Teller agrees that 10 per cent of the fossil fuel compounds would be converted to smoke when burned, some 60 per cent or more of the smoke would consist of soot with large absorption coefficients in the visible, not the 10 per cent he assumes[39,40]. Hence, Teller's estimate of potential soot emission from fossil-based fuels alone is low by a factor of some 10 × 6 = 60. A total petroleum-derived soot emission of 90 Tg is possible if major urban/industrial areas are attacked—sufficient to reduce average direct global sunlight intensities to 4% of ambient.

Realistically, absorbing and scattering particles from sources other than petroleum should also be included in the calculations. Urban combustibles (for example wood, paper, cloth, paint, household chemicals, rubber and synthetic fibres) could, we calculate, release another 10 to 100 Tg of smoke. Wildfires ignited by nuclear explosions over forest and grasslands could emit anywhere from 0 to 50 Tg of smoke. Dust would also be generated by surface nuclear detonations; attacks on hard military targets might add 10 to 100 Tg of fine scattering particles to the upper atmosphere. Powerful convective winds over fires could raise urban debris (for example, masonry dust, metal smoke, fine ash) in large quantities. In summary, it does not seem difficult, in a wide range of nuclear war scenarios, to loft sufficient sooty smoke and dust to initiate major climatic effects—especially if cities are burned.

It is also worth mentioning that explosions and fires in urban/industrial areas would release, suddenly, large quantities of toxic chemicals (pyrotoxins) into the atmosphere[2,3]. This problem remains to be fully quantified, and could provide the next departure from the conventional wisdom in studies of the consequences of nuclear war.

In his Congressional testimony, Teller[9] asserted "If you reduce the smoke by a factor of two, then instead of a temperature decrease which is sizeable, you get temperature changes which are in some cases negative, in some cases positive ... The calculations so far ... seem to show that about one-half of the smoke assumed in the paper of Turco and others, about one-half the smoke is already below the threshold [for significant climatic effects]. Now if somebody is dedicated to exaggeration, we can't stop him." In fact, as long as the smoke is injected into the upper troposphere, the abundance can be one-tenth that in our baseline case[3], or around 20 Tg, and serious climatic consequences, of at least hemispheric scale, will still follow. Regional-scale effects are likely with even smaller soot loadings.

New weapons

Teller claims that, because of a trend towards more accurate lower-yield weapons, collateral damage, ozonosphere depletion, fires and nuclear winter will, in the future, be much less likely to occur; and also that ballistic missile defence would further reduce the threat of fires and smoke. But most new strategic weapons deployments in the next decade or two will apparently involve warheads in the 100 KT to 1 MT range[16,17]. A 100 KT airburst can destroy up to 50 km². Weapons of this yield, used against industrial areas, are the ideal incendiary devices for adjacent or co-located cities; they have a quick thermal pulse, and do not produce large areas of deep rubble. Thus, the reconfiguration of nuclear arsenals now underway may be, inadvertently, a move towards a more effective stockpile of nuclear weapons for burning cities and triggering nuclear winter—unless it is accompanied by a dramatic reduction in the strategic arsenals. In addition, the Minuteman III and SS-18 missiles, with their 300 to 600 KT warheads, are likely to be with us for some time to come.

It is extremely shortsighted to assume that defensive measures against ballistic missiles will not stimulate new offensive deployments. Effective defence systems are not technically feasible or even designed, could not be deployed for decades, and when deployed would be vulnerable to direct attack, to underflying (for example, by aircraft and cruise missiles) and to relatively simple countermeasures[41–44]. The cities—and therefore the entire Northern Hemisphere, at least—will remain in serious jeopardy for the foreseeable future. It is not apparent that the peril can be significantly reduced without a major reversal of the nuclear arms race. Other reasons that low-yield weapons and strategic defence are unlikely to resolve the issues raised by nuclear winter are discussed elsewhere[6].

Teller's conclusions

Here, while Teller reiterates some of his arguments, he concludes, nevertheless, that severe climatic perturbations *could* occur after a nuclear war, threatening world populations. The only solution that he puts forward is to store food for survivors in the United States and some other (unspecified) nations.

Teller writes, "Highly speculative theories of world-wide destruction—even the end of life on Earth—used as a call for a particular kind of political action serve neither the good reputation of science nor dispassionate political thought." But, before it was widely known that there were dangers from fallout, or from ozonosphere depletion, or from climatic effects, we were not being warned that the alleged *absence* of widespread or long-term effects was speculative, or that the consequences of nuclear war might be more severe than asserted by those responsible for national policy and many of their scientific advisers. However, when a range of scientific evidence suggests that these effects are real, with grave biological and social consequences, then Teller comes forth to minimize the possible consequences, reminding us that not all the evidence is in. This, I suggest, is a clear double standard of scientific evidence at work. Teller's attempt to minimize the widespread and long-term consequences of nuclear war has in fact made possible "a particular kind of political action"—namely, the accession of ever-increasing numbers of weapons of mass destruction, beyond any military utility, and far beyond the requirements of strategic deterrence.

I have benefited enormously from discussion with my co-authors in refs 2 and 3, R. P. Turco, O. B. Toon, T. P. Ackerman, and J. B. Pollack; I am grateful to them, especially R. P. Turco, and to Hans Bethe, Paul Crutzen, Ann Druyan, Richard L. Garwin, Lester Grinspoon, John Holdren, Dorothy Nelkin, Stephen H. Schneider and Steven Soter for a critical reading of this paper.

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[From Environment, October 1985]

The Environmental Consequences of Nuclear War—Nuclear Winter: A Report From the World Scientific Community

(By Carl Sagan)

For 37 years after Hiroshima and Nagasaki, the world had been assured that, apart from radioactive fallout, there were no serious long-term environmental consequences of nuclear war. In particular, the idea that nuclear war could change the climate or even the weather was soundly pooh-poohed. Then, in 1982, Paul Crutzen and John Birks, as an incidental adjunct to quite different study on post-nuclear atmospheric chemistry, estimated that the attendant burning of forests might obscure the skies over vast areas, producing darkness at noon; [1] and later that year Richard Turco, Brian Toon, Thomas Ackerman, James Pollack, and I published an abstract of our brand-new findings that soot from the burning of cities is even more important than forest fires, that dust lofted from nuclear groundbursts can also be climatically significant, and that soot and dust together might produce a severe, widespread, and long-term cooling of much of the Earth's surface.[2]

In the following year, our studies were extended and many more cases were calculated. A five-day closed scientific meeting was held to critically evaluate the results; the findings were publicly presented; and two papers, one on the atmospheric effects [3] and the other on the biological consequences [4] of nuclear war were published. We called the climatic catastrophe "nuclear winter."

In part because the findings were so much at variance with the conventional expectations, in part because some of the relevant atmospheric physics is difficult, and in part because the results seemed to challenge prevailing views on strategic policy, misgivings and reservations were voiced in many quarters. However, a range of subsequent studies, including the first three-dimensional general circulation analysis of the problem in the Soviet Union and more sophisticated such analyses in the United States, confirmed that the potential exists for a major, at least hemispheric-scale, climatic disaster. Extensive reviews of the matter by the U.S. National Academy of Sciences [5] the Royal Society of Canada,[6] and a more superficial treatment by the U.S. Department of Defense,[7] have all concluded that there is, in the words of the National Academy report, "a clear possibility" of serious climatic consequences of nuclear war. But reservations about whether there is anything here really worth worrying about continue to linger.

The International Council of Scientific Unions (ICSU) is a worldwide consortium of scientific organizations and in some sense can be said to speak—although usually very quietly—for the scientists of the planet Earth. ICSU planned the International Geophysical Year (1957-1958) that ushered in the space age. The council has established a number of committees usually on interdisciplinary subjects. For example, its Committee on Space Research, which I know well, has since the late 1950s organized annual meetings at which Americans, Soviets, and other scientists have, in a generally very open manner, exchanged data, criticized each others' results, and even planned future cooperative ventures.

Another interdisciplinary committee of ICSU is SCOPE, the Scientific Committee on Problems of the Environment; and in response to the early nuclear winter studies, SCOPE established a sizable, multiyear, worldwide study which, in this rabbit warren of acronyms, is call ENUWAR, Environmental Consequnces of Nuclear War. The chairman of the steering committee is Sir Frederick Warner of the United Kingdom; the other members of the steering committee hail from France, Sweden,

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[1] Paul J. Crutzen and John Birks, "The Atmosphere After a Nuclear War: Twilight at Noon," *Ambio* 11 (1982): 114-125.

[2] Richard P. Turco, O. Brian Toon, James B. Pollack, and Carl Sagan, "Global Consequences of Nuclear 'Warfare'," *EOS* 63 (1982): 1018.

[3] Richard P. Turco, O. Brian Toon, Thomas P. Ackerman, James Pollack, and Carl Sagan, Nuclear Winter: "Global Consequences of Multiple Nuclear Explosions," *Science* 222 (1983): 1283-1292.

[4] Paul R. Ehrlich et al. "The Long-Term Biological Consequences of Nuclear War," *Science* 222 (1983): 1293-1300

[5] U.S. National Research Council, *The Effects on the Atmosphere of a Major Nuclear Exchange* (Washington, D.C.: National Academy Press, 1985).

[6] The Royal Society of Canada, *Nuclear Winter and Associated Effects* (Ottawa: The Royal Society of Canada, 1985).

[7] U.S. Department of Defense, *The Potential Effects of Nuclear War on the Climate: A Report to the U.S. Congress* (Washington, D.C.: Department of Defense, 1985).

Germany, India, Japan, the Soviet Union, and the United States. This remarkable study has now been published.[8]

The two volumes of the ENUWAR report strive for, and often achieve, an admirable interdisciplinary perspective and comprehensiveness. In the first volume, on atmospheric physics, there are discussions of the direct effects of nuclear detonations; nuclear war scenarios; sources and properties of smoke and dust; atmospheric processes (including the conclusions that about half the smoke produced by intense fires during a summer war could be lofted to high altitudes where they would fall out very slowly); meteorological and climatic effects (with a very useful comparison of the present bestiary of one-, two-, and three-dimensional models); chemical pollution and pyrotoxins; and radioactive fallout over timescales both of hours to days and of weeks to months.

The volume on biological effects includes discussions of general ecological principles relevant to nuclear war; ecosystem vulnerability to a nuclear winter (including computer simulations of forest ecosystems that show the possibility that long-term reductions in primary productivity could last for decades after the climate returns to normal); an extensive treatment of the agricultural consequences of nuclear war and nuclear winter; an analysis of what can and cannot be learned from the Hiroshima and Nagasaki bombings; and a hair-raising summary called "Integration of Effects on Human Populations," which predicts unprecedented worldwide mass starvation following a major nuclear war.

The body of the report is about at the level of a Scientific American article. In many cases the clarity of exposition is exemplary. There are, however, many cases where the technical detail is fairly uncompromising and even unnecessarily alarming to the unprepared reader (in one draft, for example, a curve, marked only "death," of temperature versus time illustrated a pre-nuclear-winter computer experiment in which the Sun is arbitrarily turned off and the fate of the Earth is calculated).

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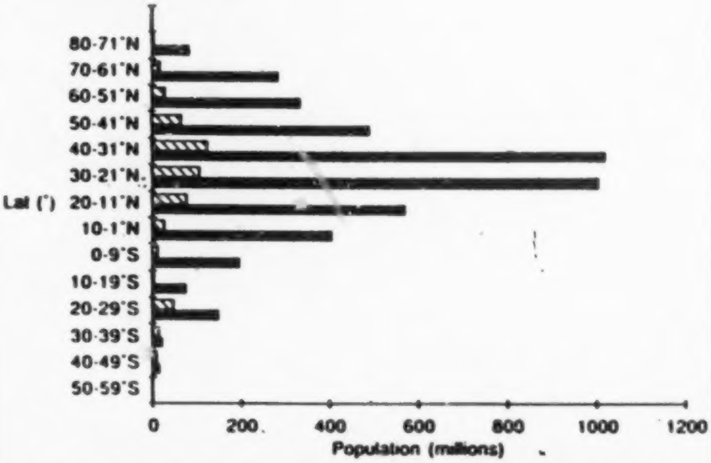
[8] Scope, *Environmental Consequences of Nuclear War*, Scope 28 (Chichester and New York: John Wiley & Sons. 1985).

FIGURE 1. Estimated deaths from starvation following a nuclear war that occurs when foodstocks are low.



Solid bars show present populations in each latitude band. Striped bars show surviving populations in same latitudes after a major nuclear war. The prompt fatalities—variously estimated to be between a few hundred million and 2.2 billion people—are not shown.

SOURCE: SCOPE, *Environmental Consequences of Nuclear War*, SCOPE 28 (Chichester and New York: John Wiley & Sons, 1985), II, 480.

The report contains many recent results—for example, a summary of the fully interactive three-dimensional global circulation models of Robert Malone and his colleagues at the Los Alamos National Laboratory, in which solar heating of dense smoke clouds propels them to very high altitudes where they survive for long periods (see Figure 1 on this page). The ENUWAR study raises the heavily qualified possibility that the temperatures in northern midlatitude continental interiors might remain as much as 10° C below normal for many years—although it is also noted that ambient temperatures might return after a year or so. Uncertainties in our knowledge are repeatedly stressed. Deficiencies in early Soviet models that tended to exaggerate the effects are mentioned, as are the limitations of recent claims that post-nuclear-war wildfires would be insignificant. But the conclusion comes through repeatedly and clearly:

No new and substantial work . . . has lessened the probability that a major nuclear exchange would cause severe environmental effects.

Despite its scale, the study leaves some topics untouched. For example, there seems to be no discussion of the possibility that sublethal doses of ionizing radiation (even as little as 100 rads) might compromise the human immune system. Indeed, the concatenation of ionizing radiation from both external and ingested emitters, pyrotoxins, increased doses of ultraviolet-B radiation, starvation, and the absence of sanitation and medical care might produce something equivalent to a global pandemic of acquired immune deficiency syndrome (AIDS).

The executive summary, like most of its counterparts in this genre, is in many places more cautious than the body of the text. The study's approach is described as "moderate in several respects." There are occasional contorted locutions such as "there is no reason to assert confidently that there would be no effects of this character." But even here, the seriousness of the nuclear winter issue breaks through:

Whatever the uncertainties, there can be no doubt that there is a considerable probability a major nuclear war could gravely disrupt the global environment and world society. . . .

As representatives of the world scientific community, drawn together in this study, we conclude that many of the serious global environmental effects are sufficiently probable to require widespread concern. Because of the possibility of a tragedy of an unprecedented dimension, any disposition to minimize or ignore the widespread environmental effects of nuclear war would be a fundamental disservice to the future of global civilization.

These last two sentences represent the concluding remarks of the foreword. Throughout, the report makes a conscious effort to avoid what it describes as "worst case" analyses, although when the stakes are this high, I believe it is well to remember what the worst case is. Nevertheless, the "middle ground" that the report strives for is appalling enough.

In its quest for "moderation" the report has avoided much use of the term nuclear winter, its authors believing that the phrase somehow conveys only the most servere climatic outcomes—drops of many tens of degrees centigrade for months or years. However, as the report itself makes abundantly clear, briefer and much less severe episodes of cold and dark will also have disastrous consequences. There are, in the ordinary progression of the seasons, both mild winters and severe ones. We have no difficulty in identifying them both as winters. Winter is the time when, over the entire hemisphere and for a significant period of time, it is darker and colder than on average. Ordinary winter is due to the Earth's revolution about the Sun and the tilt of its axis of rotation. Nuclear winter has a different cause—find obscuring particles injected into the atmosphere by nuclear war—but the phenomenon is similar, although it may be more (or less) severe. The advantage of the term as an overall description is that ordinary people can understand what is being talked about, in contrast to such circumlocutions as "anomalous climatological sequelae of nuclear war." The very apt phrase, nuclear winter, coined by Richard P. Turco, combines accuracy with clarity and should be retained.

The first volume, on the physical and atmospheric consequences, while an excellent and comprehensive summary, breaks little new ground. The second volume, by contract, has much in it that is new, and clearly indicates the jeopardy into which the United States and the Soviet Union have placed our global civilization and our species.

For most of us in affluent nations, food appears magically on our tables—or at least in our grocery stores and supermarkets—and we give little attention to how it gets there. But most food crops are the result of thousands of years of plant domestication, a vast worldwide evolutionary experiment in which mainly tropical organisms, highly temperature-sensitive, have been artificially selected. Moreover, these foodstuffs are available only because of an enormous continuing investment in animal and human labor, tractors, fossil fuels, fertilizers, pesticides, seed stocks, and transportation networks. The food on our tables is extremely vulnerable to even small changes in climate, and to any interruption of the energy and other subsidies that make modern agriculture possible.

As background for the report, technical workshops on the biological consequences of nuclear winter involving some 200 scientists from more than 30 countries were held in Paris (radiation effects); Essex, England (North Temperate agriculture); Hiroshima and Tokyo ("human effect"); Toronto (Norther Temperate ecosystems); Melbourne (Southern Hemisphere agriculture and ecosystems); Caracas (tropical agriculture and ecosystems); London; Stockholm; New Delhi; and Liningrad. Specific investigations were made of the implications of nuclear winter for agriculture in Argentina, Australia, Brazil, Canada, China, Costa Rica, India, Indonesia, Japan, Kenya, Nigeria, the Philippines, the United Kingdom, the United States, and the USSR. After assessing agricultural productivity, storage, and imports, the report concludes that the populations of Africa, Asia, and South America are especially vulnerable to starvation in nuclear winter:

Even though most of the countries of these continents have no nuclear weapons and are not likely to be targeted, the human consequences of a major nulcear war could be nearly as severe as in the principal combatant countries.

The so-called Little Ice Age, from the late sixteenth to the late seventeenth century, seems to have produced only a 1° C reduction in average summer temperatures according to the report; but this was enough to truncate the growing season in Europe by almost a month and to cause significant declines in grain yield, which in some regions were linked to starvation and epidemics. An average temperature decline that seems small—a few centigrade degrees, say—when averaged over large areas can nevertheless be catastrophic because of fluctuations from the mean.

As the average temperature approaches the freezing point, the probability that some days will be below freezing increases and, as we know from the destruction of citrus crops by short periods of unexpected freezing weather, such low temperature fluctuations can be disastrous for agriculture. An average temperature decline of more than 3° C—well within the nuclear winter projections—"is essentially unprecedented within the historical record," the report states, and would be catastrophic.

For Canadian wheat, a 2° C temperature drop hardly affects wheat production, nor does a 3° C drop for barley. But 1° C of further cooling and both crops are destroyed. The agricultural response to falling temperatures, diminished light levels, and other environmental consequences of nuclear war is starkly nonlinear. The study emphasizes that, even with no climatic perturbations, nuclear war would be catastrophic for Northern Hemisphere agriculture because of the breakdown of society and the near elimination of agricultural subsidies. And even brief temperature declines down to temperatures as high as 10° or 15° C "would substantially reduce yields of most crops in the tropics."

Because subsistence is marginal in so many parts of the world, even a small decline in available food—10 percent, say—can lead to massive starvation. Some other nations, not now in subsistence economies, are dependent on food from outside. If food imports into Japan, for example, were to cease, there would be enough food for less than half the Japanese population, and the starvation rate might be much more than half. The realities would be even worse: this projection is for the highly unlikely circumstance that Japanese agriculture continues undisturbed in the post-nuclear-war environment.

The ENUWAR report reckons that the combined effects of nuclear winter and the elimination of agricultural subsidies might cause:

> *A potential loss of about one to a few billion humans from long-term consequences; this wide range incorporates a wide range of different potential environmental and societal disturbances. This calculation does not count the losses from direct effects. . . .*
>
> *The total loss of human agricultural and societal support systems would result in the loss of almost all humans on Earth, essentially equally among combatant and non-combatant countries alike. . . . This vulnerability is an aspect not currently a part of the understanding of nuclear war; not only are the major combatant countries in danger, but virtually the entire human population is being held hostage to the large scale use of nuclear weapons. . . .*

But the report emphasizes that a total collapse of global economic and agricultural systems might not ensue, depending on the character of the nuclear war. They are merely discussing possibilities. Elsewhere, while the authors make clear that they are not projecting human survival after nuclear war, they estimate that if no more than rudimentary agriculture is possible, the carrying capacity of the planet would suffice for only some 500 million people (see Figure 2 on page 39). And if we were reduced to living entirely off natural ecosystems, as our hunter-gatherer ancestors expertly did, then the planet could support only tens of millions. There is no guarantee that this many of us would survive.

The report calls attention to and stresses (emphasis theirs):

> *The extreme sensitivity of human life on Earth to disruptions in the agricultural, economic, and societal bases that maintain populations far above the carrying capacity of natural ecosystems; i.e., the levels possible without any agricultural production. . . . The Earth's human population has a much greater vulnerability to the indirect effects of nuclear war, especially mediated through impacts on food productivity and food availability, than to the direct effects of nuclear war itself.*

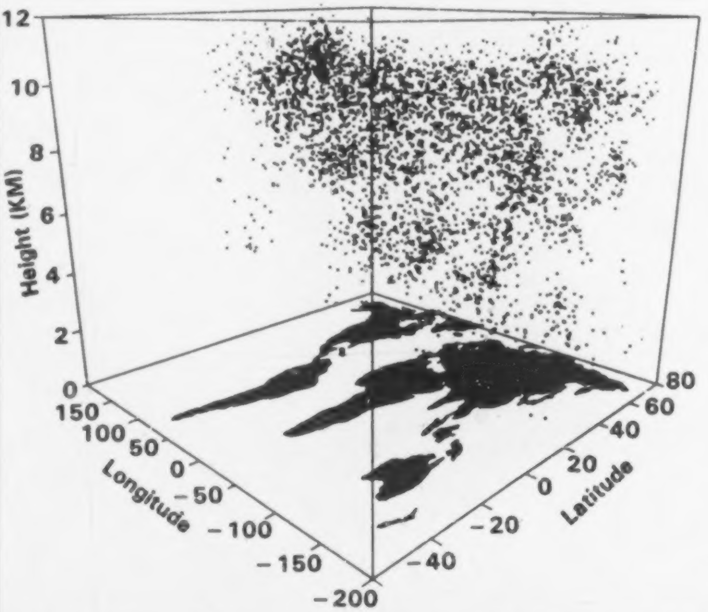
The ENUWAR study concentrates on plant species, considered one at a time, each confronted with the separate consequences of nuclear war. The authors understand very well that reality is much more complex, that the individual organisms of various species interact, and that the net biological stress will be more than the sum of the individual stresses (from radioactivity, low temperatures, low light levels, toxic smogs, changed precipitation patterns, increased near-ultraviolet radiation, and the like). What is clearly needed (and what has not yet been attempted anywhere on the appropriate scale) are what in my childhood were called terraria and aquaria—closed ecological systems in which many species are simultaneously exposed to many separate post-nuclear-war environmental stresses. Today these are called microcosms. One serious approach to the biological consequences of nuclear war would be to establish a number of such microcosms, each simulating a separate biome—a range of mutually interdependent organisms characterized by a given latitude, altitude, distance from the sea, and so on. Temperatures, light levels, radiation environments, and the like would also be controlled and the long-term development of the community of organisms monitored. Such a program would be important for the science of ecology and for the conservation of nature, quite apart from the pressing issue of nuclear war.

There is something stirring about members of the global scientific community willing to work together despite the ideological and other differences of their respective nations to address the gravest issue of our times, one that puts all of us—including scientists and political leaders—at grave risk. Legislation has been passed by the U.S. Congress and signed by President Reagan as part of the State Department authorization bill urging a major joint U.S./Soviet study of nuclear winter. However, the administration's official position, as outlined authoritatively by Assistant Secretary of Defense Richard Perle, is that such studies would be useless, because Soviet scientists have an ideological axe to grind. (Secretary Perle himself is presumably immune from this affliction.) But the ENUWAR study indicates—both on the atmospheric physics and the biological aspects of nuclear winter—how productive cooperative international studies on this subject can be.

In 1984, the U.S. government announced a $50 million five-year program to study the effects of nuclear winter. The program has since been scaled down significantly—only $5.5 million is allocated during the first fiscal year, and much of that is monies already earmarked for related studies. The administration's response is grudging and grossly inadequate. It is striking that not one penny is intended for biology. The president's science advisor, George Keyworth, has justified this on the grounds that you must first know what the environmental effects will be before you can deduce their biological and agricultural implications. The ENUWAR report itself admirably lists more than sixty relevant directions for future atmospheric research. Yet it is clear that—barring a nuclear war itself—there will never be an end to the research that can be done on a problem of this importance, complexity, and scale. Thus, as the report quite properly points out, under Keyworth's research protocol we will never study the biological effects—there will always be more atmospheric studies to do.

What is clearly needed is parameterization—that is, a detailed assessment of the biological consequences of a wide range of possible climatic outcomes of nuclear war. That is the approach successfully pioneered by the ENUWAR study, which also gives some hint of what kinds of analyses are possible for even small amounts of money.

FIGURE 2. Smoke lofting after a nuclear explosion.



Results from a crude three-dimensional computer model of the distribution of smoke particles over the planet 30 days after a global nuclear war. Each dot represents 5,000 metric tons of smoke.

SOURCE: Lawrence Livermore National Laboratory, reproduced in SCOPE, *Environmental Consequences of Nuclear War*, SCOPE 28 (Chichester and New York: John Wiley & Sons, 1985), I, 166.

I wish that the policymakers of the quarreling nuclear-armed nation-states could take to heart the implications of this report, and especially this single sentence:

A fundamentally different picture of global suffering among peoples in non-combatant and combatant countries alike must become the new standard preception for decision-makers throughout the world if the visions portrayed in this study are to remain just intellectual exercises and not the irreversible future of humanity.

[Questions submitted for the hearing record with answers supplied follow:]

QUESTIONS SUBMITTED BY SENATOR JOHN W. WARNER

FUNDING RESOURCES FOR NUCLEAR WINTER

Senator WARNER. In your judgment, is the administration providing sufficient resources to the issue of Nuclear Winter research and its policy implications. What is the principal focus of related policy research?

Mr. PERLE. Yes, the current funding for Nuclear Winter related research is correct given all of our other priorities for research. Our first objective is to reduce some of the uncertainty associated with the science, and our program is structured to attack that problem. Based on our initial policy examination and in light of what we already know about the potential effects of nuclear war, it is unlikely that we would want to change our fundamental policy of deterrence.

REDUCING COLLATERAL DAMAGE

Senator **Warner**. Setting aside questions of the validity of the "Nuclear Winter" hypothesis, what specific policy or programmatic options should we be pursuing in an effort to further minimize collateral damage? Should we, for example, pursue "earth-penetrating warhead (EPW)" technologies?

Mr. **Perle**. At the moment there are two methods to reduce unwanted collateral damage: (i) increase weapon delivery accuracy and at the same time decrease weapon yield to maintain a constant level of damage; and (ii) pursue new technologies such as EPWs that may also have some potential to reduce collateral effects. We are currently supporting research in both of these areas to support our policy of minimizing unwanted collateral damage and strengthening our deterrent.

With regard specifically to EPW, it is not clear that we should pursue this technology avenue exclusively under the premise that EPWs have the potential of reducing the cause of Nuclear Winter. We must understand more about the physics and chemistry of the phenomenon before we can determine the effectiveness of EPWs on the Nuclear Winter phenomenon.

Senator **Warner**. You mentioned that even the French independent nuclear deterrent might be enough to bring on a Nuclear Winter. What percentage reductions would be required in the United States and Soviet nuclear arsenals to bring them below the Nuclear Winter threshold?

Dr. **Sagan**. Precise numerical values are difficult and depend on such things as targeting, yield, height of burst, and so on. But it seems possible that as few as a few hundred strategic warheads might be adequate to bring about Nuclear Winter if cities are targeted. Many fewer than this, of course, might still be enough to destroy the United States or the Soviet Union as a functioning society.

Senator **Warner**. What is your policy prescription as a response to the Nuclear Winter research findings?

Dr. **Sagan**. There are obscenely too many nuclear weapons in the world—both strategic and tactical. They serve no military purpsoe and place in grave jeopardy not only the nations that have these arsenals but the rest of the peoples on this planet as well. What is urgently needed is bilateral—eventually multilateral—negotiations to bring about massive phased and verifiable reductions in the strategic arsenals of the two superpowers. This should be done in a way that does not, at any stage in the arms reduction, compromise the security of either nation. It ought to be accompanied by a Comprehensive Test Ban Treaty—which is technically and diplomatically the easiest to implement—and, for reasons that I tried to stress in my testimony, a ban on introducing weapons in space. None of these steps requires major technological advances, only political will. Perhaps by the turn of the millennium we will be able to tell our children that we have at least left them a world not much more dangerous than the one we were given.

Other implications for policy and doctrine of Nuclear Winter are discussed in the attached article from Foreign Affairs.

QUESTIONS SUBMITTED BY SENATOR EDWARD M. KENNEDY

STRATEGIC STOCKPILE

Senator **Kennedy**. Has the United States ever, since the 1960's, reduced the number of strategic nuclear weapons?

Mr. **Perle**. Yes, there were small reductions in the strategic nuclear weapon stockpile in the years: 1968, 1970, 1976, 1977, 1978, and 1981.

FUNDING FOR NUCLEAR WINTER RESEARCH

Senator **Kennedy**. In the $5.5 million earmarked for Nuclear Winter research, how much of that is new money and how much is just recycled from related earlier programs? How much is allocated for work outside of government laboratories? How much on biological or medical implications? And how much money has been set aside for the policy implications of Nuclear Winter?

Mr. **Perle**. The Interagency Research Program began in FY 1986 with a combined funding from DOD, DOE and the National Science Foundation (NSF). Of the $5.5 million now designated for research on the so-called Nuclear phenomenon, approximately $2.0 million represents increased funding over the combined individual FY 1985 funding levels of each agency.

The breakdown of the funding is as follows: DOD and DOE each contribute $2.5 million; and the NSF's share is $0.5 million. We plan to spend about 20% of this outside of government this fiscal year. Biological and medical implications comprise about 3% of the total. While funds were expended for work outside the government on policy implications of the phenomenon in prior years, this is not continued this fiscal year. Past policy related work was founded on the same gross assumptions that support the hypothesis of Nuclear Winter. The results of these past works have taken the form of parametric analyses that offer no insights into alternatives to our current policy of deterrence of nuclear war. We believe we must understand the basic science first before we consider any changes to our deterrence policies.

Senator **Kennedy**. The President and the Secretary of Defense have talked about giving SDI technology to the Soviets. How plausible is this?

Dr. **Sagan**. They can't be serious. SDI will require a battle management computer many generations more sophisticated than any computer system in existence on Earth today. But this administration has been opposed to providing even routine computer technology to the Soviets, because of the fear that it would aid Soviet military systems, including the technology of offensive weapons. Which components of SDI technology would the administration provide to the Soviets? On what time scale? Are we to imagine that the Soviets will rest content because of a promise by an American president some decades earlier that the United States would voluntarily give the Soviets the means to make U.S. strategic warheads "impotent and obsolete"?

Senator **Kennedy**. Some advocates of SDI have justified it in terms of technology spinoff. What is you reaction to this justification?

Dr. **Sagan**. It is like the argument—and it too was once seriously proposed—that the Apollo program was justified because it allegedly led to teflon cookware and cardiac pacemakers. But everyone understands that if we are interested in stickless frying pans we do not have to fly to the Moon to get them. We can decide to develop stickless frying pans directly. Every high technology endeavor, no matter how ill-conceived, will have some incidental technological benefits. But that hardly represents a good argument for the endeavor. Whatever the alleged spinoffs are, if they are essential for the American economy, let us offer contracts to develop them directly. They will cost a tiny fraction of this Maginot Line in the sky.

Senator **Kennedy**. How could it be that it took 37 years to discover this climatic catastrophe hiding in the nuclear arsenals? Why wasn't Nuclear Winter discovered earlier?

Dr. **Sagan**. I've already touched on my wish that our technical group—Turco, Toon, Ackerman, Pollack and myself—had done these calculations much earlier. But still it is striking that immense military establishments, not just in the United States, dedicated to understanding the consequences of nuclear warfare utterly failed to foresee Nuclear Winter. In fact there are declassified government studies that were devoted explicitly to "frequently neglected effects" of nuclear war that wholly overlooked, or rejected, on trivial grounds, the idea of a resulting climatic catastrophe. Perhaps it is because of the compartmentalization of military bureaucracies, but this is not only a military problem. So far as I know there is no first-rate research institute anywhere in the world devoted to seeking out previously unrecognized global scale consequences of nuclear war, or even of industrial activities associated with economic growth.

But I wonder if there is not a psychological factor at work here as well. The military establishments have by and large been in the business of reassuring everyone that nuclear weapons aren't as bad as excitable and softheaded people might have feared. There may be an institutional disinclination to look closely at the long-term worldwide consequences of nuclear war. It might give nuclear weapons a bad name. At the meeting at the Institute of Medicine that I alluded to in my testimony, some half-dozen new and adverse consequences of nuclear war were presented, aside from Nuclear Winter—and none of them was from the Department of Defense, government laboratories, or government think tanks. Why is this?

Senator **Kennedy**. Some people are worried that Nuclear Winter will weaken American resolve in the confrontation with the Soviet Union, while Soviet citizens, they say, hear nothing about Nuclear Winter. Is this true?

Dr. **Sagan**. Like previous concerns about a "bomber gap," a "missile gap," and a "window of vulnerability," we now hear occasionally about what might be called a "fear gap." But there is enough fear to go around for everybody, and sufficient cause for it. Nuclear Winter has been repeatedly discussed in Soviet newspapers, including *Pravda*, on all-Union prime time television programs, and in technical papers and books. I have myself discussed it on Soviet television, and the article "The Climatic Effects of Nuclear War," by R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack, and myself—published in the August, 1984 Scientific American in our country—was published in the October, 1984 issue of V Mire Nauki, the Soviet equivalent, with a circulation of several hundred thousand. There is at least anecdotal information that people selected randomly on the street in provincial cities of the Soviet Union, as well as the Soviet leadership, have heard about Nuclear Winter—to say nothing of the still more widely known prompt consequences of nuclear war.

Senator Goldwater. The committee is adjourned.

[Whereupon, at 5 p.m., the committee adjourned, subject to the call of the Chair.]

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